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# MANUAL
## OF
# AIR NAVIGATION
## VOL. I.

AIR MINISTRY

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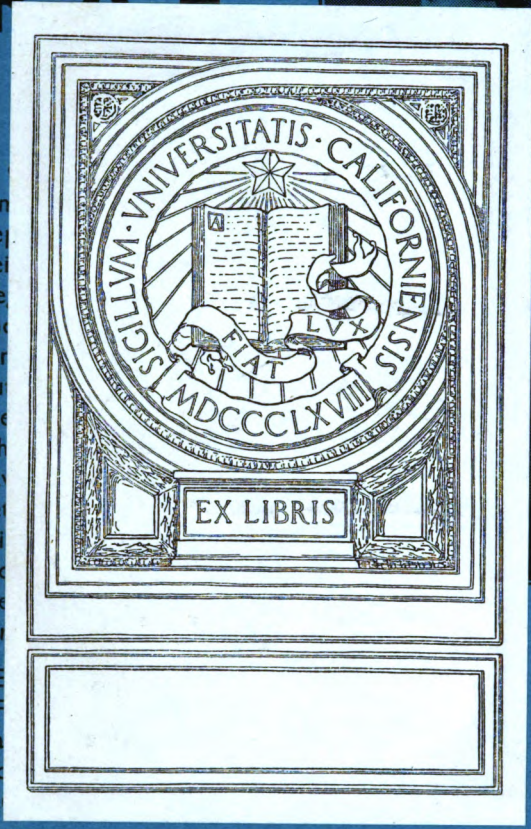


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# MANUAL OF AIR NAVIGATION

## VOL. I

Published for the information and guidance of all concerned

*By Command of the Air Council*

C. Ll. Bullock

...it.

R. MINISTRY

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## DEFINITIONS

**1.** *Air navigation* is the art of conducting an aircraft from place to place by dead reckoning and fixing position by observations of terrestrial objects and celestial bodies. It includes the ability to maintain a given direction in or above clouds and mist, and by night.

**2.** *Air speed* is the speed of an aircraft relative to the air.

**3.** *Axis of the Earth* is that diameter about which it revolves.

**4.** *Azimuth.*—*See* " *Bearing* ".

**5.** *Bearing.*—(i) The *great circle bearing* of an object is the angle at the observer between the meridian passing through the observer and the great circle joining his position to the object. This may also be called the *azimuth*. The angle is measured clockwise from the meridian from 0° to 360°. (Fig. 1.)

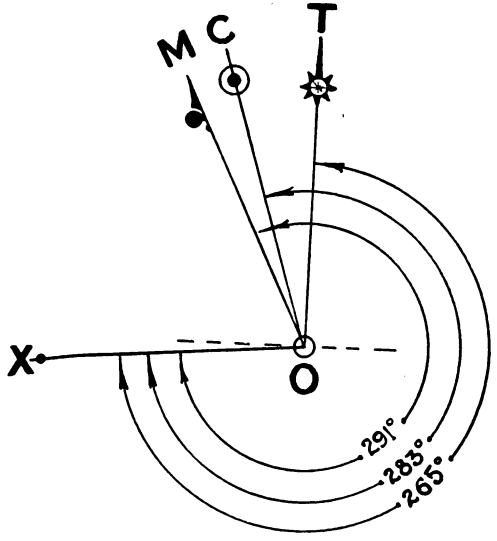


FIG. 1.—True Bearing = Angle T.O.X. = 265°.
Magnetic Bearing = Angle M.O.X. = 291°.
Compass Bearing = Angle C.O.X. = 283°.
Variation = Angle T.O.M. = 26° W.
Deviation = Angle M.O.C. = 8° E.
Compass Error = Angle T.O.C. = 18° W.

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(ii) Bearings are called *true* or *magnetic*, according to whether the angles are measured from the true meridian or the magnetic meridian.

(iii) In a *compass bearing* the angle is measured from the direction of a particular compass needle.

(iv) Bearings may be referred to the course of an aircraft, and are then measured from ahead through 180° to port and starboard, being termed respectively *red* and *green*. In Fig. 2 the bearing of A is Green 45°, and of B Red 120°.

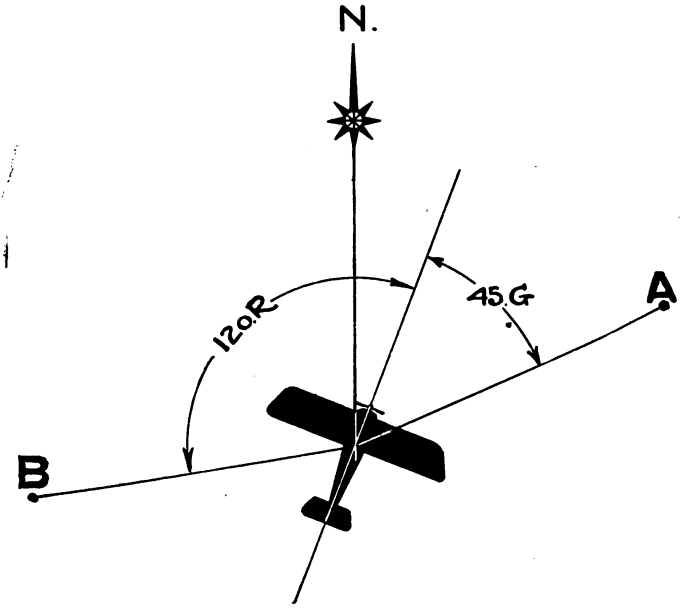


FIG. 2.—" Red " and " Green " bearings.

(v) The *mercatorial bearing* is the angle at the observer between his meridian and a rhumb line joining him to the object.

**6.** *Cardinal points.*—The directions north, east, south and west. (Usually written N., E., S., W.)

**7.** *Compass error* is the algebraic sum of variation and deviation. (Figs. 1 and 3.)

**8.** *Contour.*—The representation on a map of an imaginary line running along the surface of the ground at the same height above sea level throughout its length. A *form line* is an approximate contour.

**9.** *Conversion angle.*—The angle between the great circle and mercatorial bearings. (Fig. 4.)

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**10.** *Couple.*—When two equal forces act on a body in opposite directions, they constitute a *couple.* The couple is the product of one of the forces and the perpendicular distance between them.

**11.** *Course.*—(i) The *true course* is the angle between the longitudinal axis of an aircraft and the true meridian. (Fig. 3.)

(ii) The *magnetic course* is the angle between the longitudinal axis of an aircraft and the magnetic meridian.

(iii) The *compass course* is the angle between the longitudinal axis of an aircraft and the direction of a particular compass needle.

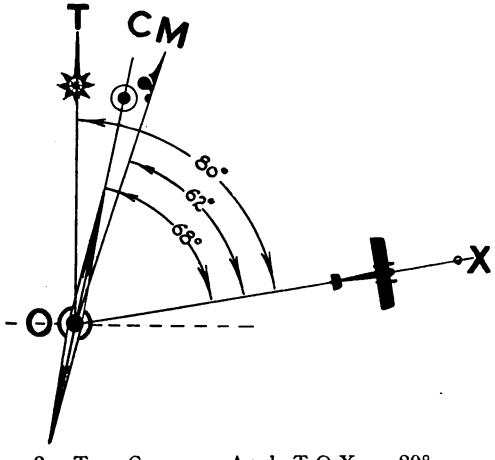


FIG. 3.—True Course = Angle T.O.X. = 80°.
Magnetic Course = Angle M.O.X. = 62°.
Compass Course = Angle C.O.X. = 68°.
Variation = Angle T.O.M. = 18° E.
Deviation = Angle M.O.C. = 6° W.
Compass Error = Angle T.O.C. = 12° E.

**12.** *Dead reckoning* consists of calculating the track and ground speed of an aircraft. The *D:R. position* is the position arrived at by dead reckoning.

**13.** *Deviation* is the angle, measured in the horizontal plane, between the magnetic meridian and the direction of a particular compass needle influenced by a magnetic field not coincident with the earth's magnetic field. It is named E. (+) or W. (−), according to whether the north-seeking pole lies to the east or west of the magnetic meridian. (Figs. 1 and 3.)

**14.** *Dip* of a magnetic needle is the angle in the vertical plane between the horizontal and the direction of the earth's line of total magnetic force. Sometimes called *magnetic inclination.*

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**15.** *Drift* is the angle between the longitudinal axis of an aircraft and the track : it is measured to port or starboard relative to the aircraft's head.

**16.** *Equator* of the Earth is the great circle of which the plane is at right angles to the axis. (W.E. in Fig. 4.)

**17.** *Fix.*—The position of an aircraft as determined on a map or chart, generally by the intersection of two or more position lines.

**18.** *Force.*—Any cause which tends to alter a body's state of rest or uniform motion in a straight line.

**19.** *Gradient.*—A rate of rise or fall, often expressed as a fraction. Thus 1/30 represents a rise or fall of 1 unit vertically in 30 units horizontally.

**20.** *Graticule.*—The network formed on a map by meridians and parallels of latitude.

**21.** *Grid.*—The representation on a map of a rectangular co-ordinate system.

**22.** *Great circle* is a circle on the surface of a sphere, the plane of which passes through the centre of the sphere and thus divides it into two equal parts. The shortest distance between any two points on the surface of a sphere is the arc of a great circle joining the points. (*See* Fig. 4.)

**23.** *Ground speed* is the speed of an aircraft relative to the ground.

**24.** *Hachuring* is a conventional method of representing hill features on a map by shading in short disconnected lines, which are drawn in the direction of the steepest slopes.

**25.** *Horizontal equivalent.*—The distance in plan between two adjacent contours. (Written H.E.)

**26.** *Inertia.*—The tendency of a body to resist a change of motion.

**27.** *Isobar.*—A line drawn on a weather map, at all points on which the atmospheric pressure has the same value.

**28.** *Isoclinal.*—A line drawn on a map or chart, at all points on which the magnetic dip has the same value.

**29.** *Isogonal.*—A line drawn on a map or chart, at all points on which the magnetic variation has the same value. The *agonic line* is the line of no variation.

**30.** *Knot* is a unit of speed : it is a speed of one nautical mile an hour.

**31.** *Latitude* of a place is the arc of the meridian between the equator and the place and is named N. or S. according to whether the place is north or south of the equator. (In Fig. 4, Lat. of A = 15° N. ; Lat. of K = 60° S.)

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A *parallel of latitude* is a small circle parallel to the equator. (HAJ in Fig. 4.)

*Difference of latitude* between two places is the arc of a meridian intercepted between the parallels of the places (written d. Lat.); d. Lat. from A to K = 75° S. (Fig. 4.)

**32.** *Layer tinting.*—A system of representing relief on maps by colouring the map between adjacent contours in a uniform shade, the shade chosen depending on the height.

**33.** *Longitude* of a place is the smaller arc of the equator intercepted between the prime meridian and the meridian of the place, and is named E. or W. according to whether the place is east or west of the prime meridian. (In Fig. 4, Long. of A = 45° W.; Long. of K = 75° E.)

*Difference of longitude* between two places is the smaller arc of the equator intercepted between the meridians of the places (written d. Long.); d. Long. from K to A = 120° W. (Fig. 4.)

**34.** *Magnetic equator.*—An imaginary line on the surface of the earth joining all points where the earth's line of total magnetic force is horizontal, i.e. where the angle of dip is zero.

**35.** *Magnetic field.*—The region round a magnet in which its magnetism has effect.

**36.** *Magnetic meridian.*—The great circle on the earth at any place in the plane of which a magnetic needle would be, if freely suspended and influenced only by the earth's magnetic field.

**37.** *Magnetic poles* of the earth are the two positions on the earth's surface where the earth's line of total magnetic force is vertical, i.e. where the angle of dip is 90°.

**38.** *Meridian* is a semi-great circle passing through the poles of the earth (NAS, NKS, etc., in Fig. 4).

**39.** *Natural scale.—See " Representative fraction ".*

**40.** *Nautical mile* is the average length of a minute of latitude measured on any meridian. Its length is generally taken as 6,080 ft. (Symbol ′.)

**41.** *Orienting* a map is the process of setting it so that the meridians on the map lie North and South.

**42.** *Poles* of the earth are the extremities of its axis of revolution. (N. and S. in Fig. 4.)

**43.** *Position error* is the error in the reading given by an air speed indicator due to the positioning of the pressure head.

**44.** *Position line* is a line obtained from observation of a terrestrial object or a celestial body, at some point on which line it is known that the aircraft must be.

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**45.** *Projection* of a map or chart is any orderly system of representing meridians and parallels and the earth's surface on a plane.

**46.** *Quadrantal points.*—The directions north-east, south-east, south-west and north-west. (Usually written NE., SE., SW., NW.)

**47.** *Representative fraction* (written R.F.).—The ratio which the distance between two points on a map bears to the distance between the same two points on the ground. The ratio is always expressed as a fraction, of which the numerator is unity. It may also be called the *natural scale.*

**48.** *Rhumb line* is that curve on the earth's surface which cuts all the meridians it meets at the same angle. (*See* Fig. 4.)

**49.** *Run* is the direction and distance over the ground which an aircraft travels between two given instants.

**50.** *Small circle* is a circle on the surface of the sphere, the plane of which does not pass through the centre of the sphere.

**51.** *Spot height.*—The record on a map of the exact height above sea level of a particular point.

**52.** *Synoptic chart.*—*See "Weather map".*

**53.** *Track* is the angle between a meridian and a line representing the actual path of an aircraft relative to the ground. It is measured from 0° to 360° clockwise from the meridian.

**54.** *Variation* (sometimes called *declination*) is the angle, measured in the horizontal plane, between the true meridian and the direction of a freely suspended magnetic needle influenced only by the earth's magnetic field. It is named E. (+) or W. (−) according to whether the north-seeking end of the needle lies to the east or west of the true meridian. (*See* Figs. 1 and 3.)

**55.** *Vector* is a straight line which, in both length and direction, represents a quantity such as a force or velocity.

**56.** *Velocity.*—The rate of change of position of a body in a given direction. Velocity therefore involves both speed and direction.

**57.** *Vertical interval.*—The difference in level between two adjacent contours. (Written V.I.)

**58.** *Weather map.*—An outline map on which are recorded meteorological observations made simultaneously at observing stations over a large area. The weather map is the basis of weather forecasting. (Also known as a *synoptic chart.*)

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# CHAPTER I.—POSITION, DIRECTION AND DISTANCE ON THE EARTH'S SURFACE

## 1. The Earth

For nearly all practical purposes the earth may be assumed to be a sphere, although it is actually an oblate spheroid. The earth rotates about an axis, the extremities of which are known as the geographic poles. In order to facilitate the fixing of position, the earth is imagined to be covered by a network of lines called *meridians* and *parallels of latitude.* Meridians are semi-great circles passing through the poles; the equator is a great circle whose plane is at right angles to the axis, and parallels of latitude are small circles parallel to the equator.

## 2. Latitude and longitude

(i) The position of any point on the surface of the earth may be defined exactly by its *latitude* and *longitude.* The *latitude* of a place is the arc of the meridian between the equator and the place, and is named N. or S. according to whether the place is north or south of the equator. Latitude is measured in degrees (°), minutes (′) and seconds (″) from 0° to 90° N. or S. The *longitude* of a place is the smaller arc of the equator intercepted between the *prime meridian* and the meridian of the place. The prime meridian is that chosen as the standard from which longitude is measured. The meridian of Greenwich is accepted in most countries as the prime meridian, though sometimes another meridian, such as the meridian of Paris, may be used. Longitude is measured in degrees, minutes, and seconds from 0° to 180° E. or W. In Fig. 4 suppose G to represent the position of Greenwich, then NGS is the prime meridian, WE is the equator. The position of the point A is :—Lat. 15° N., Long. 45° W. The position of the point K is :—Lat. 60° S., Long. 75° E.

(ii) One position on the earth's surface is related to another by the difference of latitude and difference of longitude between the places. If an aircraft is proceeding from a place F to a place T, the d. Lat. is named N. or S. according to whether the parallel of the destination is N. or S. of the parallel of the departure point. The d. Long. is named E. or W. according to whether the meridian of the destination is E. or W. of the meridian of the departure point.

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Suppose that F is in Lat. 45° 30′ N. and Long. 40° 20′ W. and T is in Lat. 60° 27′ N. and Long. 15° 30′ E. then the d. Lat. is 14° 57′ N. and the d. Long. 55° 50′ E.

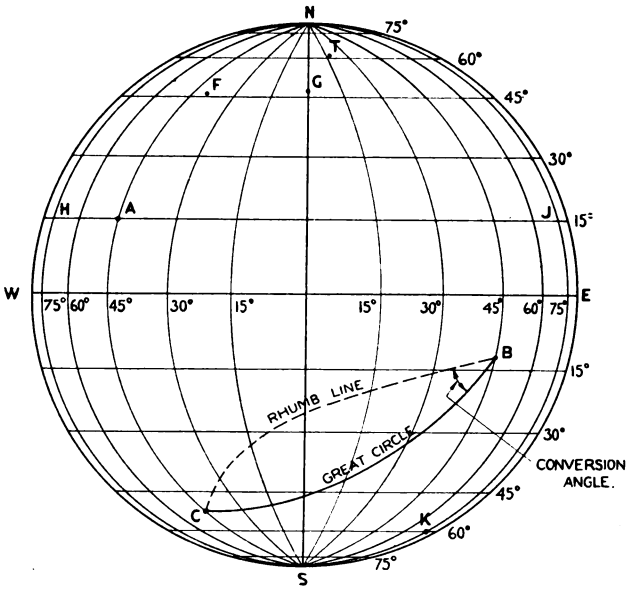


FIG. 4.—The Earth, showing latitude, longitude, great circle and rhumb line, etc.

### 3. The measurement of angles

(i) The most common system of angular measure is the *sexagesimal* method. A circle is divided into four quadrants and the angles called *right angles*. Each right angle is divided into 90 degrees (°), each degree sub-divided into 60 minutes (′) and each minute sub-divided into 60 seconds (″).

(ii) Another system is the *centesimal* method, in which the right angle is divided into 100 grades (g), each grade into 100 minutes (ᶜ) and each minute into 100 seconds (ᶜᶜ).

(iii) Latitude and longitude may be expressed in either system and therefore the method of converting angles expressed in one system to the other system should be understood. This is described in appendix I.

### 4. Bearings, courses and tracks

(i) The direction of any point on the surface of the earth is known if we know the angle at the observer between his meridian and the great circle passing through the observer and

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the point. This angle is the *great circle bearing* (sometimes called the *azimuth*) of the point. The angle between the observer's meridian and the rhumb line passing through the observer and the point is called the *rhumb line* or *mercatorial bearing* of the point. Bearings are measured from 0° to 360° clockwise from the meridian.

(ii) The *course* of an aircraft is the angle between its longitudinal axis and the meridian or, in other words, is the bearing of the nose of the aircraft from an observer in the fore and aft line of the aircraft.

(iii) The *track* of an aircraft is the angle between the meridian and the direction of the aircraft's actual path over the ground. A constant track will meet every meridian at the same angle, and is therefore a rhumb line ; thus the track from a point A to another point B is the rhumb line bearing of B from A.

(iv) Since the meridians are imaginary semi-great circles, the angle between any meridian and a particular great circle cannot be measured directly, but by the aid of a compass the direction of the meridian, and so the bearing of any point, can be determined. A compass is constructed to indicate direction under the influence of the earth's magnetism (when it is called a magnetic compass) or of the earth's rotation (when it is called a gyro-compass). All aircraft compasses indicate the course of the aircraft and some carry a device which enables the bearing of any object visible from the aircraft to be read directly from the instrument. Magnetic compasses do not, however, indicate courses and bearings with reference to the true meridian ; it is necessary to know how to convert the directions given by a compass into true courses and bearings.

### 5. Magnetic variation

It is explained in chapter XII, para. 7, that a magnetic compass needle, influenced solely by the magnetic field of the earth, does not necessarily point towards the true north, *i.e.* along the true meridian. The direction indicated by the compass needle is called *magnetic north*, and the great circle in the plane of which the needle lies is called the *magnetic meridian*. It should be noted that a magnetic meridian is not strictly a meridian, i.e. it is *not* a semi-great circle passing through the magnetic poles.

The angle, measured in the horizontal plane, between the magnetic meridian and the true meridian is the angle of *variation* (sometimes called *declination*). Variation is named E. (+) or W. (−) according to whether the north-seeking end of the compass needle lies to the east or west of the true meridian.

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## 6. Deviation of the compass

It is explained in chapter XIV, para. 1, that, owing to magnetic effects in an aircraft, a magnetic compass needle may not lie in the magnetic meridian, but may be deflected from it. The angle through which the needle is deflected, i.e. the angle, measured in the horizontal plane, between the magnetic meridian and the direction of the compass needle, is called the angle of *deviation*. Deviation is named E. (+) or W. (−) according to whether the north seeking end of the compass needle lies to the east or west of the magnetic meridian.

## 7. The relation between true, magnetic and compass bearings

(i) Bearings, courses and tracks can be expressed as *true* (abbreviation T), *magnetic* (M) or *compass* (C), according to whether they are measured relative to the true meridian, the magnetic meridian, or the direction of a specified compass needle respectively.

(ii) The method of converting magnetic to true directions and the reverse operation must be clearly understood since the conversions have frequently to be carried out in the air. It may be seen from Figs. 1 and 3 that the following rules apply:—

*Magnetic to true.*—Add easterly variation ;
subtract westerly variation.

*True to magnetic.*—Add westerly variation ;
subtract easterly variation.

Memorising these rules may be assisted by the rhyme :—

*" Variation west, magnetic best ;*
*Variation east, magnetic least ".*

*Example.*—True track from A to B is 080°. Variation 12° W. What is the magnetic track ?

Track .. 080° T.
Variation .. 12° W.

092° M. (*" Variation west, magnetic best "*)

The magnetic track is therefore 092°.

Alternatively, variation may be named + instead of *easterly* and − instead of *westerly*, and may be regarded as a correction to the *magnetic* course or bearing.

*Example.*—The magnetic bearing from an aircraft of an object on the ground is 327°. Variation 15° E. What is the true bearing ?

| *Magnetic.* | *Variation.* | *True.* |
|---|---|---|
| 327° | +15° | 342° |

The true bearing is therefore 342°.

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(iii) The method of converting compass bearings to magnetic and vice versa is similar. Suppose that an aircraft is flying on a course of N. magnetic, and that the compass has a deviation of 10° W., i.e. the N-seeking end of the compass needle is deflected 10° to the west of the magnetic meridian. It can be seen from Fig. 5 that the compass course indicated is 010°. Similarly for 090° M. the compass reading is 100° and so on, from which it appears that a westerly

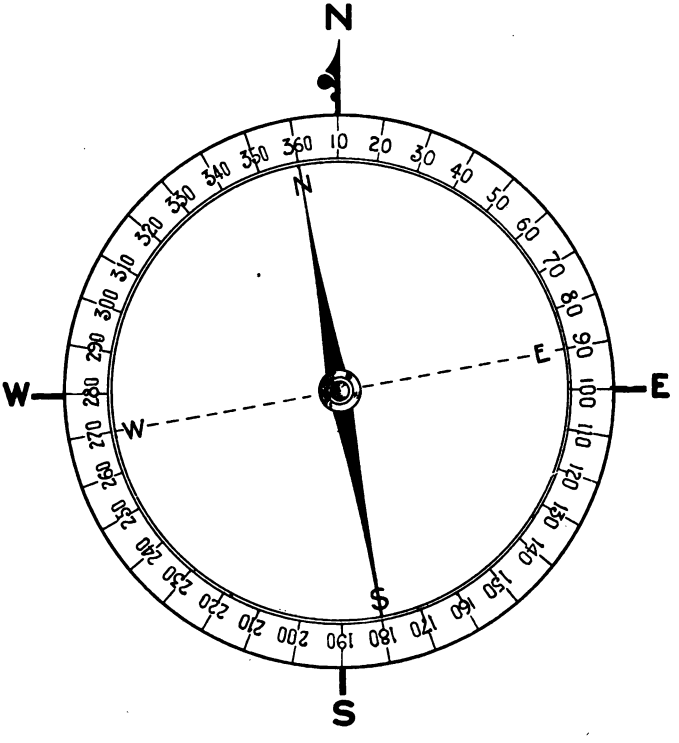


FIG. 5.—Magnetic deviation.

deviation has the effect of increasing magnetic courses by the amount of the deviation. The converse is true for easterly deviations. Hence a rhyme similar to that in sub-para. (ii) may be used :—

*" Deviation west, compass best ;*
*Deviation east, compass least."*

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*Example.*—Magnetic course 102°, deviation 5° E, what is the compass course ?

Course .. 102° M.
Deviation 5° E.

097° C. (" *Deviation east, compass least* ")

The compass course is therefore 097°.

Alternatively, deviations may be named + instead of *easterly* and — instead of *westerly*, and regarded as corrections to the *compass* course or bearing.

*Example.*—The bearing by compass from an aircraft of an object on the ground is 332°. The correct magnetic bearing is known to be 341°. What is the deviation of the compass ?

| *Compass.* | *Deviation.* | *Magnetic.* |
|---|---|---|
| 332° | +9° | 341° |

The deviation is therefore +9°, or 9° E.

(iv) As explained in chapter XIV, the deviation of a compass depends on the magnetic course of the aircraft. It is extremely important to remember this when bearings are taken by bearing compass. It may be stated as an invariable rule that *when a bearing is taken by bearing compass or bearing plate, the deviation on the course of the aircraft at that instant must be applied to it.*

(v) When an aircraft is swung for compass adjustment, as described in chapter XV, deviations are observed normally on the eight magnetic headings N., NE., E., etc. After correction, the remaining deviations are tabulated on a *deviation card* which is mounted in the aircraft beside the compass to which it refers. There are two forms of deviation card at present in use in the Royal Air Force. On Form 316 (*see* Fig. 6) the

Form 316.

| For Magnetic Course. | Steer by Compass. | |
|---|---|---|
| N. 0 | 358 | +2 |
| N.E. 45° | 41 | +4 |
| E. 90° | 85 | +5 |
| S.E. 135° | 133 | +2 |
| S. 180° | 183 | −3 |
| S.W. 225° | 229 | −4 |
| W. 270° | 273 | −3 |
| N.W. 315° | 315 | 0 |

FIG. 6.—Deviation card—Form 316.

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deviations are not usually recorded directly, but instead it shows the compass courses to steer to make good the eight magnetic courses N., NE., E. etc. There is space at the side of the card in which deviations may be written if required.

The second type of deviation card, Form 316a (*see* Fig. 7) shows the deviations on all courses in the form of a graph.

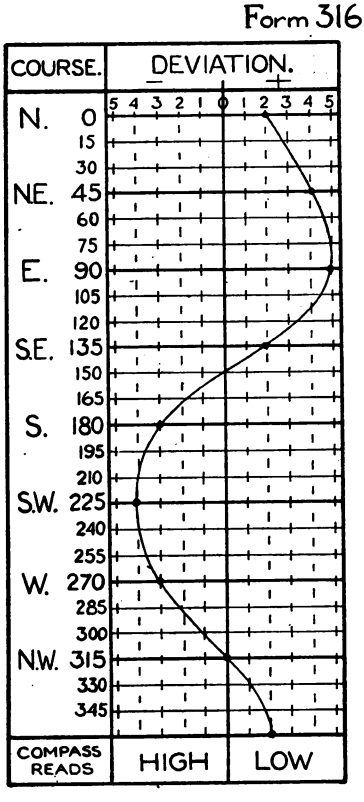


FIG. 7.—Deviation card—Form 316a.

(vi) To find the deviation on any given magnetic course is simple when Form 316a is used, as this deviation can be read directly from the deviation curve. When Form 316 is used, it is necessary to interpolate for a course other than one of the eight recorded.

*Example.*—Using the deviation card shown in Fig. 6, find the compass course to steer to make good a magnetic course of 108°.

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The deviation on 090° M. is + 5° and on 135° M. is + 2°. Thus the deviation decreases by 3° through a change of course of 45°, *i.e.*, by 1° through a change of 15°. Now the change from 090° to 108° is 18°, so that the decrease in deviation from 090° to 108° may be taken as 1° : hence, the deviation on a course of 108° M. is + 4°, and the compass course is 104°. These simple calculations can be done mentally and no difficulty should be experienced in taking out a deviation correct to the nearest degree.

(vii) To convert true bearings to compass bearings and vice versa, it is necessary to apply both variation and deviation. The following examples show how the rules are applied :—

(*a*) Find the true course corresponding to a compass course of 205° T. Variation 12° E. Deviation 3° W.

| *Compass.* | *Deviation.* | *Magnetic.* | *Variation.* | *True.* |
|---|---|---|---|---|
| 205° | −3° | 202° | +12° | 214° |

The true course is therefore 214°.

(*b*) The bearing of an object was 040° by a bearing compass when the course of the aircraft was 170° by that compass. True bearing of object 060° ; Variation 10° E. Find the deviation of the pilot's compass by which the course was 185° at the same instant.

| | |
|---|---|
| True bearing of object .. .. | = 060° |
| Variation .. .. .. .. | = 10° E. |
| Magnetic bearing of object .. .. | = 050° |
| Bearing by compass .. .. .. | = 040° |
| Deviation on course 170° in bearing compass .. .. .. .. | = 10° E. |
| Magnetic course of craft at that instant = (170° + 10°) .. .. .. | = 180° |
| Course by pilot's compass .. .. | = 185° |
| Deviation of pilot's compass .. .. | = 5° W. |

## 8. Distance and its measurement

(i) As the shortest distance between two points on a plane surface is the straight line joining them, so the shortest distance between two points on the surface of a sphere is the shorter arc of the great circle passing through the points. In Fig. 4 the black line passing through points B and C represents the arc of a great circle, so that in flying from B to C the shortest possible route would be taken by following this line. It should be carefully observed, however, that the great circle cannot be followed by flying on a constant course. Thus, at the departure point B, the great circle track is about 210°, but this changes to about 300°. Accordingly, it would be necessary

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to alter course frequently in order to fly along a great circle track. Consider next the dotted line passing through points B and C. This cuts every meridian it meets at the same angle (240°) and represents the rhumb line through the points. It will be seen that a rhumb line is a spiral about the pole. Clearly the path along the rhumb line is not the shortest distance between the points, but it offers a great advantage in that *the rhumb line joining two places may be followed by maintaining a constant true track.*

(ii) It remains to be decided whether great circle distance or rhumb line distance should be adopted for flights of average length. Consider the following comparisons :—

| From Calshot to :— | Rhumb Line Distance. | Great Circle Distance. |
|---|---|---|
| New York | 3,088 naut. miles | 2,976 naut. miles. |
| Tokio .. | 6,182 ,, ,, | 5,219 ,, ,, |

It appears that in the former case $3\frac{1}{2}$ per cent. of the rhumb line distance is saved by following the great circle and in the latter about $15\frac{1}{2}$ per cent. In shorter distances the differences are very much less. As another illustration, suppose it were required to fly from a place in the north of Scotland to a point 500 miles away to the east on the same parallel of latitude. The initial track on a great circle would be 83° T.; this track would have to be changed about 1° every 35 miles, until the final track was 97° T. The rhumb line track would be along the parallel, *i.e.* 90° T. for the whole journey. The saving in distance would be less than a mile. Thus, *for flights of normal length the difference between great circle distance and rhumb line distance is negligible.* There is no question that the rhumb line track is greatly to be preferred to the great circle track for all ordinary purposes in flying. Distances which are too great to be measured accurately by means of a scale may be calculated mathematically : formulæ are given in appendix II.

(iii) The following units of linear measure are in common use :—

(*a*) *Statute mile*—an arbitrary length which is adopted as standard in the British Empire and U.S.A. It equals 5,280 feet. Abbreviation : m.

(*b*) *Nautical mile*—the average length of a minute of latitude measured on any meridian. It is almost universally accepted as 6,080 feet. Symbol : ′.

(*c*) *Cable*—one-tenth of a nautical mile. Its length is generally taken as 600 feet.

(*d*) *Fathom*—equals 6 feet. Depths on charts are often expressed in terms of this unit.



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(*e*) *Kilometre*—the average length of one ten-thousandth part of a quadrant of a meridian. Its approximate length is 3,280 feet. Abbreviation : km.

(iv) While conversion tables for measures of length are given in appendix III, the following relations are worth memorising :—

(*a*) 6080 : 5280 as 76 : 66.
(*b*) 5280 : 3280 as 66 : 41.

Thus, 66 nautical miles = 76 statute miles ; 41 statute miles = 66 kilometres ; 41 nautical miles = 76 kilometres.

An easily remembered approximation is :—5 statute miles = 8 kilometres.

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## CHAPTER II.—MAPS

### 1. Types of maps

Maps are of various types, designed according to the purpose for which each is to be used. The projection of a map, the scale, the features shown and the amount of detail—all depend on the purpose of the map. Thus there are physical maps, showing the main features of mountains, rivers, etc., to the exclusion of other detail; road maps, on which roads are particularly emphasised; atlas maps, showing towns and international boundaries but little more; and so on. Of special air maps there are very few: in most countries the maps used for flying are adaptations of ordinary topographical maps on a suitable scale.

### 2. Scale of maps

(i) The scale of a map is the relation between a given distance on the earth and the length of that distance as measured on the map. Scale may be expressed in the following ways:—

(*a*) *A statement in words*, showing the relation between any unit on the map and any other on the ground. For example, " one inch to one mile " means that one mile on the ground is represented by a map length of one inch. Large scale maps are often mentioned colloquially with reference to a ground unit of one mile; thus the " six-inch " and " quarter-inch " maps are respectively six inches and one-quarter inch to 1 mile. On the other hand, the small scale maps are described in terms of a map unit of one inch; thus the " 10-mile " map has a scale of 10 miles to 1 inch. In countries which use the metric system of measurement, the scale can be expressed in terms of kilometres to one centimetre.

(*b*) *A representative fraction* (or *natural scale*)—e.g. 1/20,000. This is always expressed as a fraction having the numerator one. Its meaning is that one unit of length on the map represents the number of the same units on the ground given by the denominator. The unit of length employed is immaterial. Colloquially the R.F. is frequently used to describe a map in the form " the 20,000 map ", " the million map ", etc.

(*c*) By means of *a graduated scale line*. The construction of scales and the conversion from one method of indicating the scale to another are dealt with in appendix IV.



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(ii) The scale of a map largely determines the amount of detail which can be shown on it. Thus on a 10-mile map it is impossible to show every minor road and track, whereas on a scale of 25 inches to the mile every building can be shown. On a small scale map it is often necessary to exaggerate certain important features. For example, on a $\frac{1}{4}$-inch map a road of average width would, if shown exactly to scale, appear as a mere hair line, and therefore it is necessary, in order that roads may easily be followed on the map, to exaggerate their width. Thus it must not be expected that the map will give an exact representation of all the minor features on the ground. A sharp and well-defined bend in a road, for example, may not be shown at all on the map and detail sometimes has to be shown away from its true position. The amount of detail possible in maps of different scales is illustrated in Fig. 8.

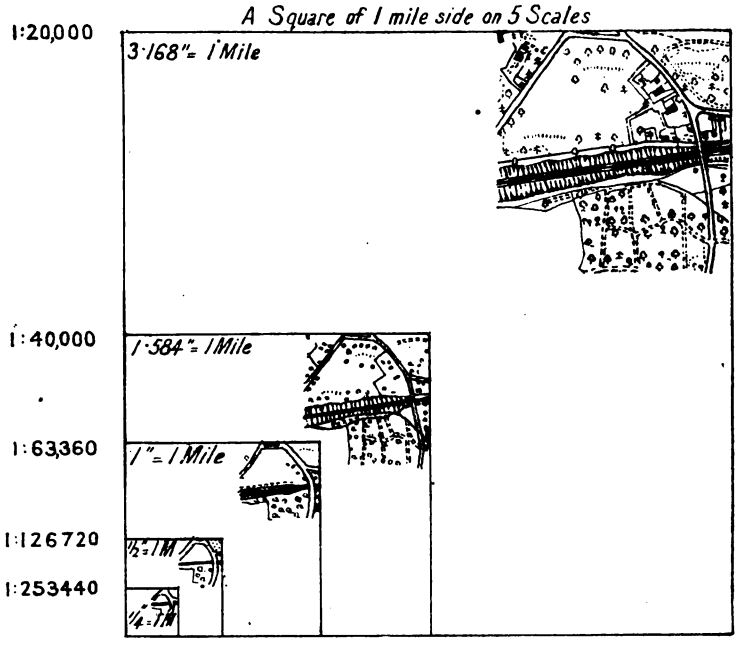


FIG. 8.—Relative detail on maps of different scale.

### 3. Map projections

(i) A map projection may be defined as any orderly construction to represent the meridians and parallels of the earth on a plane surface. Since the earth is approximately spherical in shape, it is impossible to represent any portion of its surface

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on a plane surface without some distortion. If a perfect map were possible, the scale would be the same everywhere on it, and it follows that :—

(*a*) All areas on the earth would be correctly represented by corresponding areas on the map at a given scale.

(*b*) All shapes on the earth would be represented by exactly similar shapes on the map.

(*c*) Bearings measured on the map would correspond exactly with bearings on the earth.

No one projection can secure all these desired properties, and therefore various projections have been devised to preserve, as far as possible, one of the properties by sacrificing others, or alternatively to effect a compromise and to even out all the errors.

(ii) When using a map or chart it is essential to understand the properties of the projection on which it is drawn. The majority of Admiralty charts are on Mercator's projection, though some large-scale charts are on the Gnomonic projection. Maps are on various projections, such as Cassini's, Transverse Mercator, Polyconic, and others. The properties of the more important projections are described in A.P. 1456, Manual of Air Navigation, Vol. II, Part 2. The properties of Mercator's projection are also described briefly in chapter III of this manual.

(iii) For practical purposes, the properties of the projections on which maps used for flying are constructed (with the exception of Mercator's projection) are as follows :—

(*a*) Meridians are curves or straight lines converging towards the nearer pole. If they are curves, the curvature is often so small as to be inappreciable.

(*b*) Parallels of latitude are curves which are concave towards the nearer pole. On any but very large scale maps, the curvature is appreciable.

(*c*) A straight line drawn between any two points A and B on the map may be assumed, for all practical purposes, to represent the great circle between A and B. The angle between the line AB and the meridian through A may be taken as the great circle bearing of B from A. The maximum error involved in making this latter assumption is of the order of 1° in a distance of 500 miles.

(*d*) On large scale maps the scale may be assumed to be constant over the area shown on the map. In the R.A.F. edition of the $\frac{1}{4}$-inch map of England and Wales the maximum scale error is about 1 in 2,500. On small scale maps where the scale varies considerably scales at different latitudes are usually printed in the bottom margin of the map. Distances measured on maps are approximately great circle distances.

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(iv) For distances within the normal range of modern aircraft great circle bearings and distances may be measured from the map. For long flights, great circle tracks and distances may be calculated (*see* A.P. 1456, Manual of Air Navigation, Vol. II), or great circle tracks may be laid off on a Gnomonic chart, on which straight lines accurately represent great circles, and then transferred to the maps used in the air. It should be remembered, however, that the great circle cannot be followed by flying on a constant course. (*See* chapter I, para. 8.)

**4. Relief**

(i) The representation of relief on maps is of primary importance. On maps used for air navigation, is it essential that the height and position of the highest points of hills should be clearly shown and that sufficient detail should be given to facilitate the recognition of prominent features. The various methods by which relief can be shown are :—

(*a*) Contours and form lines.
(*b*) Hachures.
(*c*) Hill shading.
(*d*) Layer tints.
(*e*) Spot heights.

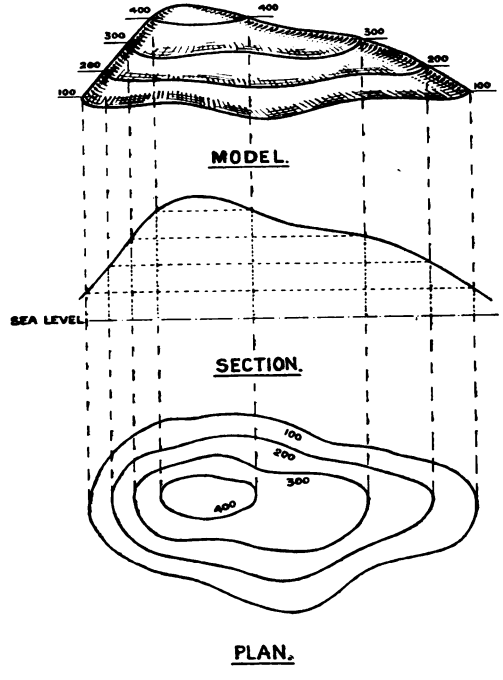


FIG. 9.—Relief shown by contours.

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(ii) A *contour* may be defined as a line running along the surface of the ground at the same height above mean sea level throughout its length. Contours are laid down by instrumental observation, which is a lengthy and costly process. *Form lines* are approximate contours, drawn in by eye, and are not to be relied upon for accurate information. The difference in altitude between two successive contours is called the *vertical interval* (V.I.). The interval used depends on the scale and purpose of the map: on the ¼-inch Ordnance Survey map the V.I. is 200 feet, on the 1-inch map it is 50 feet. Contours undoubtedly constitute the most accurate method of showing hill features. The gradient of a slope may be obtained by measuring the distance in plan (the *horizontal equivalent*) between two adjacent contours. Thus, suppose the V.I. to be 200 feet and the H.E. 1,800 feet, the gradient is 200/1,800, or 1/9. The comparative steepness of a hill can be readily gauged if it is remembered that the contours lie more closely together on the steeper slopes, but it should be noted that this is only true when the V.I. is constant.

(iii) *Hachures* are lines drawn down the direction of steepest slope. On the steeper slopes, the lines are drawn more heavily and closer together. They give a good general idea of the shape of the ground, but very little positive and detailed information. Hachuring is seldom used.

(iv) *Hill shading* is similar in principle to hachuring. The shading may be applied to all slopes according to their degree of steepness, or it may assume a light which is supposed to cast a shadow. Like hachuring, it tends to obliterate other important detail, and is seldom used.

(v) *Layer tinting* consists of colouring the map between certain contours by tints which vary with the level. Generally, green is used for heights immediately above sea level, with light green and shades of light and dark brown as the height increases. When differences in level are considerable, a layered map is very easily read, since the relief stands out as on a model, but it is not possible to show minor variations of height, and an impression may be given that the ground between contours is level. This method has the disadvantage of being expensive, owing to the number of separate printings required, and also heavy colouring of the map may make the reading of detail difficult.

(vi) *Spot heights* are definite points shown on a map with the exact height above mean sea level printed against them. On hachured or shaded maps they give the only exact information as to level contained on the maps. For showing minor relief features between contours, spot heights are

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very useful. The datum line from which all heights are measured in Ordnance Survey maps is the mean sea level at Newlyn, Cornwall.

(vii) On most topographical maps, a combination of two or more of the methods described above is used.

**5. Conventional signs and lettering**

(i) Conventional signs for various features of importance (e.g. railways, churches, aerodromes) are used so that the necessary information may be given clearly without overcrowding the map. Lists of the conventional signs with their meanings are usually printed in the map margins.

(ii) The lettering on maps is not chosen haphazard: a particular style is used on the same series of maps for the names of features of the same class.

(iii) A table of conventional signs for aeronautical information as agreed to by the International Commission for Air Navigation is given in appendix V. Conventional signs for use in marking maps and diagrams for operational purposes are shown in appendix VI.

**6. Grids**

(i) It is essential to be able to refer to some definite point on a map. A simple method of defining the position of a point on a plane is to give its perpendicular distance from each of two *axes* (i.e. from two selected lines intersecting at right angles). These perpendicular distances are called *co-ordinates*. In Fig. 10, NS and EW are the axes. Their

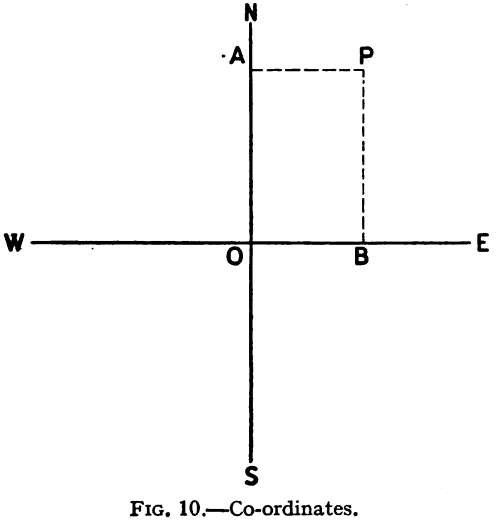


FIG. 10.—Co-ordinates.

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point of intersection O is called the *origin* and PA and PB are the co-ordinates of a point P. On a map, it is usual to choose a meridian near the centre of the area concerned and to use this as the axis NS. A point on this axis is chosen as origin and the axis EW is drawn through this point at right angles to NS. The co-ordinates PA and PB are then termed respectively the "*easting*" and "*northing*" of P.

By a mathematical convention, co-ordinates measured to the right of the axis NS are positive while co-ordinates measured to the left are negative. Similarly, co-ordinates measured above EW are positive and those measured below are negative. To avoid the necessity of using negative signs in map references, the origin is transferred to some point well to the south-west of the area concerned, and lines drawn through this "*false origin*" parallel to NS and EW are used as axes.

Co-ordinates can be expressed in any convenient units, such as yards or metres, tens of yards or metres, hundreds of yards or metres, and so on, according to the scale of the map and the degree of accuracy required. The easting is always stated first, followed by the northing.

(ii) If co-ordinates alone are used to define positions on a map, it will be found that many points lie so far from the axes that the co-ordinates run into several figures and are far too large for convenient measurement. To overcome this difficulty, lines are ruled on the map, parallel to the axes, at specified distances from each other. These distances may be thousands or tens of thousands of yards or metres, or any other convenient intervals, depending on the scale of the map. The system of squares formed by these lines is known as a *Grid*. For convenience in giving references the grid squares are lettered in accordance with a regular plan, and the co-ordinates of a position are given with reference to the nearest grid lines to the west and south of it, so that a grid reference will consist of one or more letters followed by the figures of the co-ordinates.

(iii) A rectangular grid cannot be extended indefinitely. The area which can be covered by the grid depends on the projection on which the map is drawn: the maximum area that can be covered by the projection, and consequently by the grid, has to be limited so that the permissible errors of scale and bearing are not exceeded.

### 7. The modified British grid

(i) This form of grid is used on the R.A.F. editions of the 10-mile map of Great Britain and the $\frac{1}{4}$-inch map of England and Wales and of Scotland, the military edition of the 1-inch O.S. map, and on some maps of India, Iraq and the Far East.

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(ii) In the military and R.A.F. edition maps of Great Britain, the origin lies on the meridian of Dunnose Head, in the Isle of Wight, longitude approximately 1° 12′ W. This meridian forms the north-south axis of the grid, Dunnose Head being the origin. A " false origin " is chosen well to the south-west of the Scilly Islands.

The grid unit on maps of Great Britain is the metre, and grid lines are drawn at 500,000-metre (500-kilometre) intervals, forming squares, known as *primary* squares, whose sides are 500 kilometres in length. Each primary square is subdivided by grid lines drawn at 100-kilometre intervals into 25 squares, the sides of which are 100 kilometres in length, these squares being called *secondary* squares. Both the primary and the secondary squares are lettered according to the plan shown in Plate I at the end of the book. Thus each secondary square is indicated by two letters, the first of which refers to the 500-km. square in which it is situated.

(iii) The position of any point is defined by means of its easting and northing from the nearest grid lines to the west and south of it. To facilitate the measurement of co-ordinates, additional grid lines are drawn at convenient intervals depending on the scale of the map. On the ¼-inch and 10-mile maps, the interval is 10 kilometres. On the ¼-inch map, lines are numbered by figures given on the face of the map and on the edges of the sheet, and the letters of the grid squares are printed several times in each square, so that both the numbers and the square letters can be read when the map is folded. (*See* Plate II.) On the 10-mile map, every fifth line only is numbered, and the square letters are printed only once in each 100-km. square. The smaller figures printed at the sheet edges are for giving the full co-ordinates relative to the false origin and should normally be ignored.

To give the grid reference of any point, take the west side of the small square in which the point is situated and read the figure printed on this line or count from the nearest figure visible. Then estimate the number of tenths of the square eastward from the line to the required point. Thus two figures are obtained, giving the easting. Follow a similar procedure to obtain the northing. These four figures then give the co-ordinates of the point with reference to a 100-km. square, the square being specified by the letters printed on the map.

To consider an example, refer to Plate II, which contains portions of four 100-km. squares.

Andover Aerodrome is found to lie in square (v) U and its co-ordinates are 7766, since it is seven tenths to the east of the line numbered 7 and six tenths to the north of the line numbered 6. Thus the full grid reference is (v) U 7766. If the (v) were omitted, it will be seen from Plate I that the point

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referred to might equally well be in Hampshire, in the North Sea near Berwick, or in the Shetland Islands, the shortest distance between two places with the same reference being 500 kilometres, or about 300 miles. When both letters are given, the nearest place with the same reference will be five times as distant, i.e., about 1,500 miles.

On the 10-mile and ¼-inch maps, co-ordinates are estimated to tenths of a 10-kilometre square and therefore the four-figure co-ordinates obtained give positions correct to the nearest kilometre, or slightly over half a mile.

For practice the following grid references should be verified on Plate II :—

| | | | |
|---|---|---|---|
| Hamble Aerodrome .. | .. | (v) U | 9128 |
| Chalton Church .. | .. | (w) Q | 1736 |
| Exton Church .. | .. | (w) Q | 0541 |
| Atherfield Point .. | .. | (v) Z | 8899 |

(iv) On the 1-inch O.S. map, grid lines are drawn at 10-kilometre intervals, as on the other maps. Additional lines are also drawn at 1-kilometre intervals (*see* Plate III). Co-ordinates are found in exactly the same way as on the 10-mile and ¼-inch maps, but there are now three figures for the easting and three for the northing. Thus there will be six figures in each reference, giving the position to the nearest tenth of a kilometre, or slightly over 100 yards. The letters of the grid squares are not printed on the map, but a plan showing the incidence of letters is given in the margin of the map.

As an example, verify that the grid reference of Chalton Church is Q 169356. (Compare with the co-ordinates measured on the ¼-inch map.) The nearest point with the same reference is 300 miles away, as before, but if the letter were omitted the nearest similar reference would be only 60 miles distant.

(v) Although the grid unit on maps of Great Britain is the metre, the modified British grid is also used with the yard as the unit. Plate IV shows a portion of the 1/25,000 map of Singapore Island : it should be noted that the scale is more than twice that of the map in Plate III. Grid lines are drawn every 1,000 yards, and positions may be given to the nearest 100 yards, the nearest point with the same reference, without a grid letter, being about 60 miles distant.

### 8. Other systems of reference

(i) Another method of indicating a point on a map or chart is to give its bearing and distance from some easily located landmark or seamark. This method is more often used for giving positions on charts than on maps. The position should always be given in the same form, for example 180° Eddystone 25′, which refers to a point 25 nautical miles south of the Eddystone lighthouse.

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(ii) *Squared maps.*—Each map sheet is regarded as an individual map and is divided into sections consisting of squares which are formed by drawing straight lines usually parallel to the sheet edges at convenient distances apart, for instance, two inches. The position of a point may be found by reference to the square in which it is situated, the squares being identified by letters and numbers printed either in the margins or on the face of the map. In order to limit the search for a particular place and to fix its position accurately, its co-ordinates with reference to the west and south edges of each square may be given.

The disadvantage of squared maps is that the system of squares is peculiar to one individual map sheet, so that, in order that a reference shall not be confused with a similar reference on another sheet, it is necessary to specify also the particular map sheet.

(iii) *The graticule.*—The graticule consists of meridians and parallels of latitude drawn at convenient intervals, dividing the map or chart into sections (which are not true squares). Thus it is a simple matter to define the position of a point by its latitude and longitude or, alternatively, by reference to the section in which it is situated, the sections being identified by letters or figures in the same way as on squared maps. Scales of latitude and longitude are given in the margins of most maps so that, whether the graticule is printed or not, the latitude and longitude of a point can be taken from the map.

### 9. Tracks and bearings on maps

(i) On most maps used for flying, a straight line represents a great circle, very nearly. (*See* para. 3.) A great circle bearing may therefore be laid down on a map by drawing a straight line. Tracks, however, are rhumb lines, and therefore a straight line drawn between two points on the map does not accurately represent the track between these points. For flights of normal length the difference is very small, and it can generally be assumed that a straight line drawn between two points on the map represents the track required. Unless the track is due north or south, however, the angles made by this line with the meridians of the departure point and the destination will not be the same, owing to the fact that the meridians on the map are not parallel, but converge towards the nearer pole, and therefore the angle from true north should be measured by means of a protractor from the meridian midway between the departure point and the destination. If the meridian is not shown on the map, it may be convenient to draw part of it in pencil, by joining a point on the longitude scale at the top of the map to the corresponding point on the longitude scale at the bottom of

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the map. On gridded or squared maps, a grid or square line may be used instead of a meridian, but it must be remembered that, owing to the convergence of the meridians, these lines are not parallel to the meridian required. The deviation of the grid (or sheet edges in the case of a squared map) at the east and west edges of the map sheet is usually printed in the margins, and the deviation at any other point on the map can be found by interpolation and added to, or subtracted from, the angle measured. It is worth while to remember that, on maps of Great Britain with the modified British grid, the grid deviation is zero on the meridian of 1° 12′ W.

(ii) Tracks and bearings measured on maps are true tracks and bearings. When magnetic bearings are required, the magnetic variation must be applied. (*See* chapter I, para. 7.) The angle of variation is generally printed on the map, together with the date and the annual rate of change. On some maps, where the value of the variation changes over the area covered by the map, this information is repeated at several points on the map. Double compass roses are printed on some maps, one compass rose being based on the true meridian and the other on the magnetic meridian, so that a required bearing may be referred to the magnetic compass rose by means of a parallel rule or Douglas protractor.

### 10. The R.A.F. Edition ¼-inch Ordnance Survey map

(i) For short distance flying a map on a scale of about ¼-inch to a mile is found most satisfactory. Sufficient detail can be given on the map to facilitate map reading and the scale is such that a map sheet of convenient size covers an area approximately 100 miles square.

(ii) The standard short distance flying map for the Royal Air Force is at present a modified form of the ordinary O.S. ¼-inch topographical map. Relief is indicated by contours, layer tints and spot heights. The green layer tints for heights from 0 to 400 feet have been deleted, allowing green to be used for woods and orchards, and these distinctive features, which are very useful as landmarks, stand out prominently on the map. Golf courses and race courses, as being possible landing grounds, are shown by special conventional signs. Railways, which are very easily seen from the air, are shown by heavier lines than on the ordinary maps. For an air map it is desirable that roads should be shown with a degree of prominence corresponding to the clearness with which they can be seen from the air. A main road, perhaps tarred and in places obscured by trees, may not show up to a pilot nearly as distinctly as a mere footpath crossing a field. In the R.A.F. edition the colouring of roads has been toned

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down, since the original map was primarily a road map. Aerodromes, landing grounds, prohibited areas, airway obstructions, and other details which are of importance for air navigation purposes are given special conventional signs. which are printed on the map in red. An explanation of these conventional signs, which have been agreed to for international use, is printed in the margin of each map sheet.

England and Wales are covered by 12 sheets and Scotland by 10. Sheet No. 1 is common to both countries. The grid is superimposed on the maps in purple, the same colour being used for compass roses, which are printed in at least two places on each sheet. Information is given as to the value and the annual change of variation on each sheet, and the amount of deviation of the grid from true north on the east and west sides of the sheet.

(iii) A further modified version of the ¼-inch map is under consideration. A great deal of superfluous detail, particularly names of rivers, hills, small villages and so on, has been omitted, thus simplifying the reading of the map.

**11. Other maps in use in the Royal Air Force**

(i) *The 10-mile map of Great Britain, R.A.F. edition.*—This map is very similar to the ¼-inch map but, since the scale is considerably smaller, the amount of detail shown is less. The conventional signs for aeronautical information are the same as on the ¼-inch map, but are printed in blue: aeronautical landmarks, golf courses, race courses and ground signs are omitted. Compass roses are also printed in blue and the grid is superimposed in purple.

England, Wales and Scotland are covered by three sheets, each sheet measuring 38 × 26 inches and overlapping the adjoining sheet 6 inches.

(ii) *Maps in use in commands overseas.*—Maps used by the Royal Air Force overseas are produced by the Geographical Section, General Staff, by the Survey of India, or by local survey authorities. They are obtained either from the Air Ministry or by local purchase, except in India where arrangements for the supply of maps are made by the Government of India.

These maps are on various projections and various scales, the most common scales being 1/1,000,000, 1/500,000, 1/250,000 and ¼-inch to one mile. No special air maps are at present in use, the maps used being ordinary topographical maps, though some have aeronautical information overprinted on them.

(iii) *International maps.*—The International Commission for Air Navigation laid down details of several series of international air maps, the individual sheets to be produced

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by the various countries concerned. Only a few sheets of each series have, however, been published. The only international map of which a number of sheets is available is the International 1/1,000,000. This is not primarily an air map, though some modified sheets on this scale have been produced for air use. The map is constructed on the International Polyconic projection, each sheet covering 4° of latitude and 6° of longitude.

**12. Correction of maps**

Alterations, additions or deletions to be made to R.A.F. maps are notified in "*Air Ministry Orders*". The following standard method of correcting maps must be carefully observed :—

(i) All alterations, additions or deletions must be made in red ink, except for temporary corrections. Temporary corrections must be made in pencil, and either entered in ink or rubbed out when a further notice of confirmation or cancellation is received. Erasures from maps must never be made: when necessary, details to be corrected must be crossed through in ink.

(ii) The year and number of every Air Ministry Order from which corrections have been made are to be entered at the lower left-hand corner of the map. Thus, suppose corrections to have been made from A.M.O's. A.196/33, A.65/34 and A.74/34, these would be entered as follows :—

(33) A.196 — (34) A.65 — A.74 —

(iii) The detail of information inserted on the map in the form of additions and corrections must correspond with the detail printed on the map and must be entered in a similar style as far as possible.

(iv) Information existing on the map must not be obliterated by any additions or corrections that may be made.

(v) When notes are to be added to a map they must be written in a convenient and conspicuous place.

(vi) When marking the positions of aerodromes, landing grounds, units, etc., on maps the appropriate conventional signs as set out in appendices V and VI should be used.

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## CHAPTER III.—CHARTS

### 1. Projections of charts

(i) Practically all charts used in the Royal Air Force are on Mercator's projection. For general navigation purposes it is very convenient that a rhumb line (which is the path of an aircraft steering a constant course in a calm) should be represented by a straight line, and also that the angle at the meridian which represents the course should be shown by an equal angle on the chart. These features are secured on the chart by drawing meridians as parallel straight lines at right

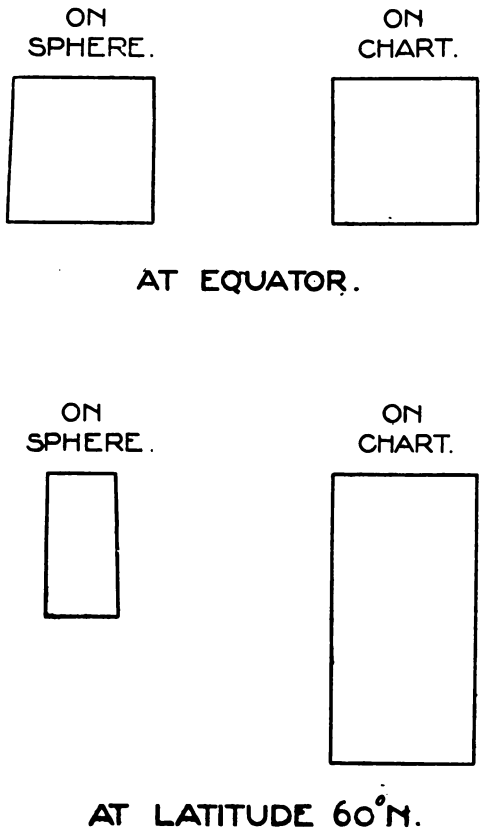


FIG. 11.—Area on a Mercator's chart.



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angles to the equator. The equator, being a rhumb line, is represented by a straight line on the chart and all parallels of latitude appear as straight lines parallel to the equator and at right angles to the meridians.

(ii) On the sphere the length of 1° of longitude is 60 geographical miles at the equator and zero at the poles. On a Mercator's chart, however, since the meridians are parallel, the length of a degree of longitude is the same in any latitude. Thus, suppose a chart were constructed to a scale of 3 inches to 1° of longitude at the equator, a degree would also measure 3 inches in latitude 60° (or any other latitude), although in latitude 60° on the sphere a degree of longitude is actually only half as long as at the equator. In order to preserve the correct shape of portions of the earth's surface, the scale of latitude is increased in the same proportion as the scale of longitude. It follows that :—(*a*) there can be no uniform scale of distance on a Mercator's chart, and (*b*) areas are exaggerated in high latitudes.. In Fig. 11 the relative sizes of areas enclosed by 1′ of latitude and 1′ of longitude on the earth, and as represented on a Mercator's chart, are compared at the equator and in latitude 60° N.

(iii) Some charts are constructed on the Gnomonic projection, but these are not commonly used for air navigation. The special feature of the Gnomonic projection is that it shows all arcs of great circles on the sphere as straight lines on the chart. A Gnomonic chart is of use in long distance navigation because it allows the shortest distance between two points to be laid down at once by a straight line, but apart from this it has practically no useful features ; bearings, shapes and areas are all distorted, and there is no constant scale of distance.

### 2. Latitude and longitude on charts

Mercator's charts are, as a rule, graduated on the left and right hand edges for latitude and at the top and bottom for longitude. Generally, the larger the scale of the chart the greater the number of sub-divisions. The divisions of the longitude scale are only to be used for laying down and taking off the longitude of a place, and on no account must they be used for measuring distance. Since 1′ of latitude is equal always to one nautical mile, the latitude scale is used for measuring distance.

### 3. Bearings on charts

(i) Rhumb line bearings are given absolutely accurately on Mercator's charts. The graduated circles which are generally printed on charts make it a simple matter to lay down or take off a bearing, either true or magnetic : the circles are called " compass roses." These are illustrated in the table of signs

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and abbreviations to be found at the end of the book (Plate V). The usual form of " compass rose " consists of two circles, clearly separated from each other. The outer is graduated from 0° to 360° clockwise and gives true bearings. The inner circle gives magnetic bearings and is graduated in two ways :—

(*a*) Outside in degrees from 0° to 90° east and west from north and from south, and

(*b*) in points and half points on the compass.

Neither of these two systems is used in the Royal Air Force. The inner graduations of the magnetic circle should be disregarded and when the outer graduation is used, care must be taken to distinguish between the method of naming bearings used in the Royal Navy, and that used in the Royal Air Force. Thus a magnetic bearing of 160° is sometimes named S.20° E. in the Royal Navy. The variation in the region represented on the chart is given on the " compass rose " with the annual rate of change. Bearings can be conveniently laid down or taken off from the " compass rose " by means of parallel rulers or the protractor on a Chart Board ; they should be referred always to the nearest " compass rose." As all meridians are parallel straight lines, true bearings may alternatively be referred to a meridian by means of a protractor.

(ii) Great circles are not shown as straight lines on Mercator's charts. Since W/T bearings are great circle bearings, they must be converted to rhumb line bearings. The method by which this is done is discussed in Chapter VI, para. 6.

**4. Scale of charts**

The scale is generally given on an Admiralty chart in the form of a " natural scale," that is, a representative fraction. Since the method of projection renders it impossible for there to be any constant scale of distance on a Mercator's chart, the natural scale can only be correct for some given latitude, and as a general rule the natural scale refers to the middle parallel of latitude shown on the chart. Consider a chart drawn to a scale of 6 inches to 1° of longitude at the equator. Then 6 inches on the chart represents 60 geographical miles on the earth. Sixty geographical miles = (60 × 6,087 × 12) (= 4,382,640 inches). Then the natural scale is 1/730,440 *at the equator*. The meridians being parallel, 6 inches would represent 1° of longitude in any latitude. Now in latitude 60° the length of 1° of longitude is 30 miles. Then the natural scale would be 1/365,220 *in latitude* 60°. The scale of a Mercator's chart may also be given in the form of a connection between distance on the chart and longitude. As, for example, " scale = 3 centimetres to 1° longitude."



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## 5. Measurement of distance on charts

The length of a *rhumb line* between two places on a Mercator's chart is always referred to as the " distance." From what has already been written it should be clear that as latitude increases, parallels of latitude become wider apart. This can be seen from any Mercator's chart by measuring the length representing a given difference of latitude at the bottom and at the top of the latitude scale. Suppose in Fig. 12 that A, B, C, D represent parallels of latitude on a chart and E, F, G, H a rhumb line. It is evident that the whole distance EH could not be measured accurately by referring it either to the latitude scale between A and B or that between C and D. The distance EF could, however, be measured on the scale between A and B, the distance between F and G on the scale between B and C, and so on. Thus, in practice, distances up to 100 nautical miles may be measured with satisfactory accuracy by taking the distance between them on the chart by means of dividers and referring it to the scale of latitude and distance at a point roughly opposite the middle latitude of the two places. A distance considerably greater than 100 nautical miles—and especially if the difference of latitude is great—should be divided into sections, and each section measured by the latitude scale opposite to it. If greater accuracy is required, the distance must be calculated according to the rules given in Appendix II. *The scale of longitude must never be used for measuring distances.*

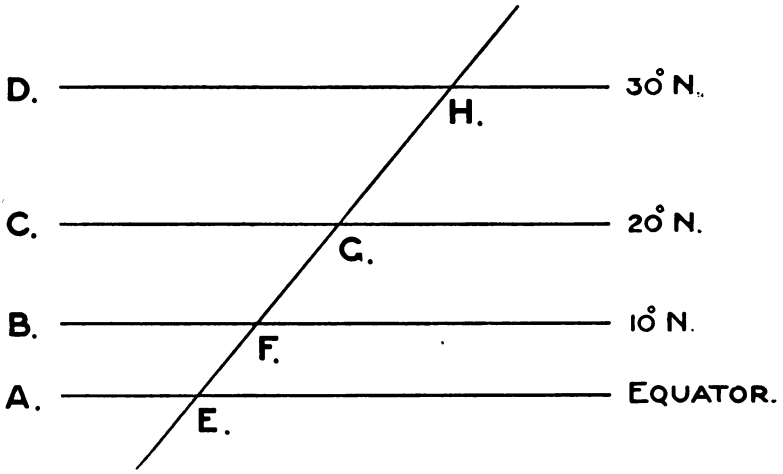


FIG. 12.—Scale on a Mercator's chart.

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**6. Conventional signs**

Conventional signs on charts are necessarily of a totally different type from those used for maps and some signs on Admiralty charts may have little interest to the airman. A complete list of signs and abbreviations used on Admiralty charts is given on a plate at the end of the book (Plate V).

**7. Systems of lights**

(i) Lights round the coast may be of great importance to pilots at night, but it should be realised that the lights shown in Admiralty charts are designed to be of assistance to surface craft, and not to aircraft. Thus, lights are sometimes screened to landward and, although lights will generally be visible to a high flying aircraft through a much greater range than to surface craft, it is possible that the pilot will not see a light if the aircraft passes above or nearly above it. Lights may be either steady and continuous or be varied by the introduction of flashes, eclipses, etc. They are divided into two classes :—

(*a*) Lights of which the colour does not alter through an entire system of changes, and

(*b*) Lights which alter in colour.

(ii) The abbreviations used in describing lights and the characteristics of lights are as follows :—

F.—Fixed. A continuous steady light.

Fl.—Flashing. (*a*) Showing a single flash at regular intervals, the duration of light being always less than that of darkness.

(*b*) A steady light with at regular intervals a total eclipse, the duration of light being always less than that of darkness.

Gp. Fl.—Group flashing, showing at regular intervals a group of two or more flashes.

Occ.—Occulting. A steady light with, at regular intervals, a sudden and total eclipse, the duration of darkness being always less than, or equal to, that of light.

Gp. Occ.—Group occulting. A steady light with, at regular intervals, a group of two or more sudden eclipses.

F. Fl.—Fixed and flashing. A fixed light varied at regular intervals by a group of two or more flashes of relatively greater brilliancy. The group may, or may not, be preceded and followed by an eclipse.

Rev.—Revolving. Light gradually increasing to full brilliancy, then decreasing to eclipse.

The abbreviation " Alt." (alternating) in conjunction with any of the above signifies that it changes its colour.

" (U) " after the name of a light indicates that it is unwatched, and therefore must not be implicitly relied on.

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(iii) The *period* of a light is the interval between successive commencements of the same phase, i.e., in a flashing light the interval between the commencement of one flash and the commencement of the succeeding flash, and in an alternating occulting or group flashing light, etc., the time occupied by the exhibition of the entire system of changes included in the same phase.

(iv) The distance of visibility of a light given on a chart is calculated for a height of eye of 15 feet. There are three factors which may cause the visibility of a light on a clear night to differ from the distance given in the chart, viz. :—

(*a*) refraction,

(*b*) height of observer's eye differing from 15 feet.

(*c*) height of tide.

(v) An example of a light as designated on a chart is :—
Lt. Alt. Fl. W.R. ev. 30 sec. (U) vis. 11 M.

Such a light would show every 30 seconds one white and one red flash. It would be visible 11 miles from an observer 15 feet above sea level. The light would be unwatched.

(vi) Particulars of lights are given in the Admiralty List of Lights, Fog Signals and Visual Time Signals. This publication contains full information about all lighthouses, light vessels, fog signals and visual time signals throughout the world. It is kept up to date by amendments published in Admiralty Notices to Mariners and by annual supplements.

## 8. Correction of charts

Charts must be kept corrected up to date. The rules laid down in chapter II, para. 12 for the correction of maps apply generally to charts, with the following exceptions :—

(i) Admiralty charts, after first publication, are kept corrected by means of new editions and new issues on which large corrections have been carried out.

(ii) Small corrections are notified from time to time in Admiralty Notices to Mariners and, when a chart is corrected from information promulgated in these notices, the year and number of the notice are entered in the bottom left-hand corner of the chart, e.g. :—

*Small corrections* 1934—*903*—

(iii) When a chart is corrected from information which is considered of no importance from the standpoint of safe navigation and which is, therefore, not promulgated in an Admiralty Notice to Mariners, the year, if not

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already shown, and date of the correction are entered on the chart in sequence with the notations referred to above, in one of two ways, e.g. :—

*Small corrections* 1934—[5.20]—*or*

*Small corrections* 1934—(VI. *25*)—

These indicate that the chart received minor corrections on the 20th May or 25th June, respectively.

(iv) Corrections from temporary or preliminary notices should be inserted in pencil and the year and number of the notice shown against them, e.g., N.M. $\frac{742}{1934}$ temp. ; and also in the botton left-hand corner of the chart *below* the small corrections notations.

**9. Chart folios.**

Charts are issued in folios, each folio containing all the charts of various scales normally required for navigation in the area to which it applies. On the outside of each folio is its number and title, e.g., " Folio 107. Firth of Forth to Thames Entrance," and a list of the charts that it contains. On the back of each chart is a label, bearing the number of the chart and its title, the reference and serial number of the folio, and the consecutive number of the chart in the folio. For example, the label might read :—.

2182A. North Sea, Southern sheet.

(Folio No. 107. Serial No. 81. Consecutive No. 13).

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## CHAPTER IV.—MAP READING

### 1. General considerations

(i) The term " map reading " means to the soldier the art of interpreting the topographical features and general appearance of a portion of the earth's surface by the examination of a map on which it is represented. The ability to read a chart implies to the seaman nothing more than a clear understanding of all the conventional signs and information given upon it. The airman must be conversant with maps and charts in these senses, although not perhaps in such detail as is necessary for the soldier and seaman, but he must also make use of maps and charts in the air and so become familiar with an aspect of map reading peculiar to himself. This special knowledge of map reading involves the ability to recognise features on the ground while moving at high speeds and from greatly varying heights. Although satisfactory maps have been adapted for use in the air, few specially made aeronautical maps are at present in existence. Hence it is necessary that maps originally drawn as topographical maps for use on the ground should be used in air navigation. It may be useful to consider maps generally as to the degree in which they adequately represent ground features. It has already been stated that a scale generally considered most satisfactory for air navigation maps is $\frac{1}{4}$-inch to a mile. It is therefore impossible for anything approaching a perfect picture of the earth's surface to be shown on the map, as it is not feasible to reproduce a picture a quarter million times reduced. An excessive amount of detail would make a map very difficult to read in the air and, above all other considerations, maps for use in the air must be clear to read. Clearness can only be obtained by omitting a great many features from the map, and by using conventional signs to represent many of those features which are included because of their importance as distinctive landmarks, or for other reasons.

(ii) Map reading, either on the ground or in the air, calls for a clear understandng of the scale of the map and a " sense " of that scale when using the map, of the direction of true or magnetic north, and of the conventional signs used. It may sometimes be convenient to convert the scales on foreign maps into one of the systems used in Great Britain. (*See* appendix III.) The direction of true north should rarely be in doubt ; it must, however, be remembered that the right and left hand edges of the sheet are not always parallel to the meridians, and the lines on squared or gridded maps

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must not be confused with meridians. The magnetic variation of the locality covered by the map is generally clearly stated. The meanings of conventional signs soon become familiar with practice. The key to a chart is the title, and this should be carefully read through first. In the title the locality covered, the date of survey, and a list of abbreviations will be found. Whether a map or a chart is to be used, its date should be considered, and when any choice is possible, the map or chart of the latest date must always be used; and it should be ascertained that it has been properly corrected up to date.

**2. Folding a map or chart**

The correct arrangement of the maps or charts to be used in the air should be completed on the ground before the beginning of the flight. The desired track between the place of departure and the objective should be laid down on the map: more than one sheet may be necessary. Whenever possible the maps should be carried in a chart board, and they should be arranged in the order in which they will be required. If a chart board is not carried, the map should first be folded so that the whole of the track is visible. It should then be folded to a convenient size and carried in such a way that successive sections of the track can be seen by turning over the folds one by one. The R.A.F. ¼-inch map is now issued in folded sheets. The necessity for opening out a map completely in the air should always be avoided. It should also be arranged that necessary information, such as the latitude and longitude scales on charts, and the distance scales on maps, are readily accessible.

**3. Landmarks and seamarks**

(i) *Landmarks* :—

(*a*) *Water*.—This can generally be seen at a great distance and rivers, lakes, &c. are as a rule very clearly marked on the map. After wet weather it must be remembered that large areas of low-lying country may be temporarily flooded: these flood areas are sometimes difficult to distinguish from lakes. Some small streams shown on the map may not be visible on the ground through being obscured by trees.

(*b*) *Railways*.—These are nearly always distinctive and useful landmarks in England and the East: they are not such good landmarks on the Continent. Railway crossings or junctions are specially prominent.

(*c*) *Woods*.—Shape is the chief consideration. It must be borne in mind that woods may have been cut down since the date of publication of the map.

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(*d*) *Roads.*—It is sometimes difficult to distinguish a main road from an unimportant one. Main roads are usually tarred, and are therefore less conspicuous than some secondary roads. Cross roads are sometimes good landmarks. The newly constructed arterial roads afford good landmarks, particularly where the surface is of concrete.

(*e*) *Towns.*—Towns are generally to be identified readily. The general colour of towns varies in different districts. The positions of the church and railway station may help in identifying a town, as may the directions in which railway lines leave and enter it.

(*f*) *Golf Courses.*—These generally are fairly good landmarks and are possible landing grounds. Golf courses are indicated on the R.A.F. Special Edition Ordnance Survey maps by small flags.

(*g*) Large private houses, windmills, gasometers and cemeteries may all prove useful as distinctive landmarks, but are not specially marked as a rule on topographical maps.

(ii) The individual characteristics of a landmark are very rarely as important to the pilot as the relationship of the landmark to other features in the neighbourhood. For example, a particular church may be a prominent mark, but it is quite likely that another church a few miles away from it will look very much the same from a height of 5,000 feet. But suppose a church is noted as lying about a mile west of a railway junction and about two miles north of a large wood, it is unlikely that it will be mistaken for any other church within a large area.

(iii) *Seamarks.* (*a*) *Sandbanks, rocks and shoals.*—A rock will show up very clearly and makes an excellent mark. These marks may be covered or uncovered, according to the state of the tide.

(*b*) *Lightships.*
(*c*) *Large buoys.*
(*d*) *Main steamer tracks.*
(*e*) *Cliffs.*—These often have distinctive colours.
(*f*) *Light-houses.*
(*g*) *Conspicuous towers, buildings,* &c., near the coast.

**4. Flying by map reading**

Skill in map reading does not begin and end in the ability to pick up conspicuous landmarks and to locate them on the map. Further, and most emphatically, map reading does not consist in following conspicuous landmarks such as rivers,

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railways or coast lines. When weather conditions are favourable a pilot efficient in map reading should be able to follow a direct track to his required destination by map reading alone. To do so he must be able to locate on the map minor features visible on the ground. This calls for a considerable degree of skill which can be acquired by careful methodical practice, and in no other way. The difficulties of map reading are naturally greater at lower altitudes and it would be found a very useful practice to fly over unfamiliar country having few distinctive landmarks at heights which decrease as the pilot's proficiency improves.

**5. Map reading at night**

(i) The degree of visibility at night varies according to atmospheric conditions and to the light shed by the moon; but whatever may be the conditions, ability to see at night, to distinguish ground features and to estimate distance can be developed by careful training.

(ii) Visibility by night changes much more than by day on account of the varying amount of light given by the moon; an accurate estimate of the value of reconnaissance can, therefore, only be arrived at if the conditions prevalent at the time are carefully weighed.

(iii) Even on clear moonlight nights every small detail cannot be distinguished without the aid of artificial light, and the first view of an object is generally a dim outline. Trees play a large part in hindering observation, not only by the cover which they afford, but by the shadows they cast. On full and half-moon nights when the moon is low, the effect of shadows cast by trees and other ground features is very great, and pilots should be warned against confusing these shadows with ground objects.

(iv) On clear moonlight nights, the following ground features are generally distinguishable :—

(*a*) Woods and forests—are very useful landmarks on clear nights and can be recognised up to a great altitude.

(*b*) Rivers and lakes—being good reflectors of light, are easy to distinguish even on comparatively dark nights. By moonlight, on clear nights, stretches of water can be distinguished even from great altitudes, especially when the district under observation lies between the observer and the moon.

(*c*) Roads and railways are useful landmarks. Roads which are untarred are more visible than tarred roads, and this fact adds to the difficulty of map reading as most maps, being designed primarily for road users,

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give prominence to the main roads which are usually tarred. After rain, untarred roads tend to blend with the adjacent land and are less clearly visible. When bordered by trees, roads are less conspicuous, particularly on moonlight nights when the moon is low and the shadows long. Railways can be seen on moonlight nights by the reflection of the light from the rails, but are not easy to follow on dark nights. Trains, especially if steam or smoke is being emitted from the engine, can be seen from a great altitude owing to the reflection of the fire on the steam or smoke. The general direction of railways and main roads, and the relations they bear to each other and to neighbouring landmarks should be kept in mind. Passing trains or motor-car headlights are often of assistance in determining the direction of a railway or road.

(*d*) Towns and villages can often be seen from a distance by their lights, and can generally be identified by their shape and the appearance of the roads or railways running through them. It should be borne in mind that many of the lights are extinguished at an early hour and that the towns or villages are therefore less conspicuous, and appear to have changed their shape, during the later hours of the night.

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## CHAPTER V.—THE TRIANGLE OF VELOCITIES AND ITS APPLICATION

### 1. The parallelogram and triangle of velocities

(i) A velocity is the *rate of change of position in a given direction* so that it involves both speed and direction. Any velocity may conveniently be represented by a straight line, called in mathematical language a *vector*. By employing a suitable scale the speed may be represented by the length of the line and by using a suitable reference line the direction may be shown relatively to that line. In the graphical solution of problems it is convenient to consider north to be at the top of the paper: a meridian should be drawn and the scale employed should be clearly stated.

(ii) A body may be subject to two or more velocities simultaneously and these velocities may or may not act in the same straight line. For instance, suppose a ship to be steaming at 8 knots down-stream in a river flowing south at 3 knots. Clearly the speed made good by the ship southwards is the sum of 8 knots and 3 knots. Steaming up-stream the speed made good is 5 knots in the direction north. When two or more velocities act on a body at the same time they are called *component* velocities. Thus, in the example given the component velocities are 8 knots south and 3 knots south, and in the second, 8 knots north and 3 knots south. The velocity equivalent to two or more component velocities is called the *resultant* velocity. It is seen that when two components act in the same straight line the resultant is obtained by addition or subtraction.

(iii) When two component velocities act in directions other than in the same straight line, the resultant may be found by means of the *parallelogram of velocities*. Suppose that a ship steams north at 10 knots when the tide is running at 4 knots, 120°. It is required to find the ship's resultant velocity. In Fig. 13 let A represent the position of the ship. Then AB represents the velocity of the ship and AC that of the tide. Complete the parallelogram ABDC and join the diagonal AD.

Now imagine that the two component velocities acted separately for one hour each. If the ship steamed north at 10 knots with no tide running it would arrive in one hour at the position represented by the point B. If for a second hour only the tide affected the ship, she would drift to the point represented by D. When the two velocities act at the same time, the result is the same, that is, the ship arrives at the

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point D in one hour and it is found from the diagram that her resultant velocity is 8·7 knots, 25°. The conclusion arrived at may be expressed quite generally as follows :—*If two component velocities acting at a point be represented in magnitude and direction by two straight lines drawn from the point and a parallelogram be constructed on the two straight lines, then the resultant velocity is completely represented by the diagonal of the parallelogram drawn from the point.*

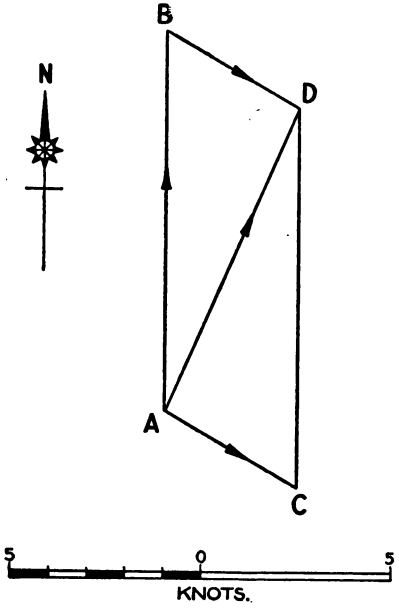


FIG. 13.—The parallelogram of velocities.

(iv) Reverting to Fig. 13, it will be seen that the same result could be obtained by using only the triangle ABD instead of the whole parallelograms. It is nearly always preferable to solve problems of this kind by the triangle of velocities. It should be carefully noticed that the arrow heads on the lines AB and BD which represent the component velocities follow each other round and oppose that on the line of the resultant velocity. This invariably applies, and arrow heads should always be used to show the direction of the velocities distinctly. Stated formally, the theory of the triangle of velocities is, *if a moving point A possesses simultaneous velocities represented by the two sides AB and BC of a triangle, taken in order, these are equivalent to a velocity represented by the third side of the triangle AC.*

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## 2. The effect of wind on an aircraft in flight

(i) Suppose that an aircraft is steered in the direction BC (*see* Fig. 14), which is the prolongation of its fore and aft axis AB. If there is no wind its actual path over the ground will be BC, and the speed relative to the ground will be the same as the air speed.

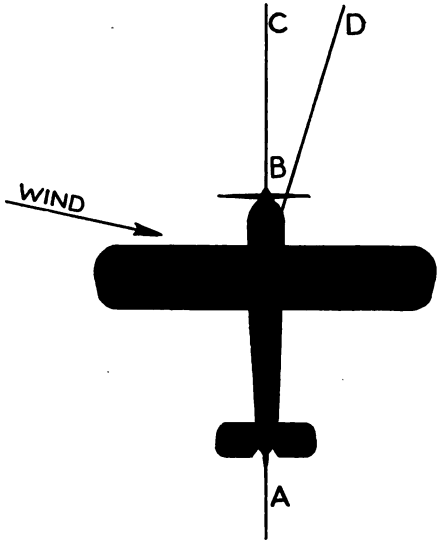


FIG. 14.—The effect of wind on an aircraft in flight.

(ii) Suppose that a wind blows in the direction shown. Then, although the direction of the aircraft is kept parallel to BC, its actual path relative to the ground will be in some direction BD, called the *track*, and its speed relative to the ground, called the *ground speed*, will not necessarily be the same as the air speed. The angle CBD is the *angle of drift*.

(iii) The aircraft is acted upon by two component velocities one being the course and air speed, the other the direction and speed of the wind. The resultant velocity constitutes the track and ground speed. There are thus six factors which constitute the three velocities of the triangle of velocities. A knowledge of any four of these is sufficient to complete the triangle, from which the remaining two factors may be determined. Problems involving the triangle of velocities can be solved graphically or by some form of course and distance calculator.

(iv) When the problems are solved graphically, the directions of the velocities must always be shown by drawing



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arrow heads on the lines representing them, single arrows being used for courses and wind directions and double arrows for tracks.

### 3. To find the course to steer to make good a desired track

(i) *Example.*—To find the course to steer to make good a track of 80° T. Wind velocity 315° T. 25 m.p.h., air speed 80 m.p.h. (The direction *from* which the wind blows is always given.) (*See* Fig. 15.)

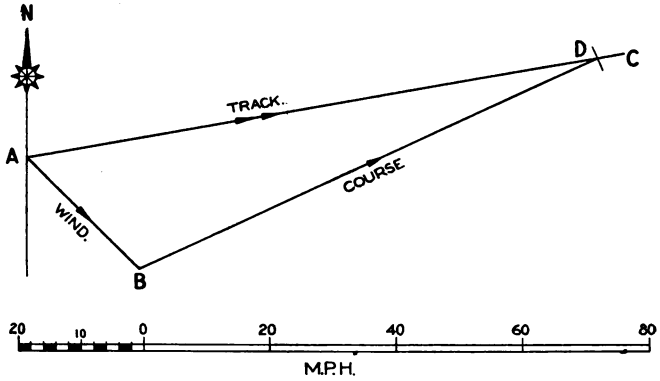


FIG. 15.—To find the course to steer allowing for drift—by plotting.

Draw NA to represent the true meridian.

From A draw AB in direction 135° to represent 25 m.p.h. to a suitable scale. Then AB represents the wind (*down wind*).

From A draw AC, 80° to represent the track.

Open a pair of dividers or compasses to represent 80 m.p.h. (air speed) to scale, and from B cut AC at the point D. Join BD.

The triangle of velocities is now complete; the angle between BD and the true meridian represents the true course. This is found by means of a protractor to be 65°.

The length of the line AD represents the ground speed. This is found by measurement to be 92 m.p.h.

(ii) *To solve the example above by C.D.C. Note.*—In solving problems with the C.D.C. 9-inch, Mark I, which is described in chapter XI, para. 7, the following points should be borne in mind :—

(*a*) Directions are read from the side of the arm on which the indicator of the movable pointer lies.

(*b*) The direction of any of the lines parallel to the central arrow can be read from the graduation cut by the central arrow.

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(*c*) The two sides of the triangle of which the lengths are known always meet at the centre of the instrument. That is, the two arms are used for those two sides.

(*d*) Always imagine the triangle of velocities superimposed on the arms of the instrument and especially consider the direction of the arrow heads.

(*e*) Check the result roughly by applying common sense to the problem. If, for instance, an aircraft were steering an easterly course and the track made good was south of east, then the wind must be from some approximately northerly direction. Again, if the ground speed be greater than the air speed, the wind must be from a direction behind the aircraft.

The sides of which the lengths are known in this problem are those representing wind and air speed. Proceed as follows (*see* Fig. 16) :—

Set the head of the central arrow to the desired track, 80°.

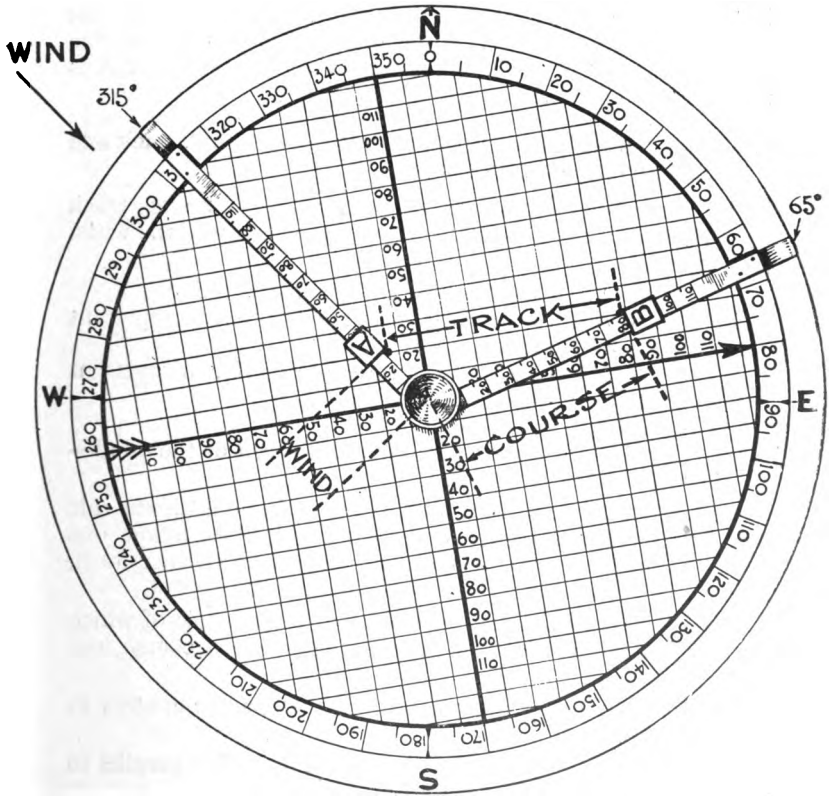


FIG. 16.—To find the course to steer allowing for drift—by C.D.C.

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Set one arm to the direction from which the wind is blowing, 315°, and the pointer on it to the wind speed, 25 m.p.h.

Set the pointer on the other arm to the air speed, 80 m.p.h. Turn this arm until the pointer on it is over the particular line on the disc parallel to the central arrow over which the pointer of the wind arm lies. (To avoid placing the air speed arm wrongly, it should be remembered that the course which it indicates will be more or less in the direction of the central arrow which represents the track.)

The direction of the arm on which the air speed was set gives the course, 65°.

The ground speed is found by counting the divisions between the indicators on the arms. It is seen to be 92 m.p.h.

By comparison with Fig. 15, it will be seen that the point B in the figure is represented by the centre of the C.D.C. AB in the figure is represented by the arm A of the C.D.C., and BD in the figure by the arm B of the C.D.C. The line AD in the figure is represented by the line joining the pointers on the arms of the C.D.C. It is worthy of note that the point A is not represented by the centre of the C.D.C.

**4. To find the velocity of the wind ; course, air speed, track and ground speed being known**

(i) *Example.*—Course 56° M., air speed 75 knots, track 70° M., ground speed 60 knots. Find the velocity of the wind. (*See* Fig. 17.)

Draw NA to represent the magnetic meridian.

From A draw AB in the direction 56° M. to represent 75 knots to a suitable scale.

From A draw AC in the direction 70° M. to represent 60 knots to the same scale.

Join BC.

Then BC gives the direction and speed of the wind—from 15° M. at 22 knots.

The direction of the wind should never be in doubt if the rule that the directions of the component velocities follow one another round be remembered. Expressed in another form, the rule is "*wind blows from course to track*".

(ii) *To solve by C.D.C.*—The sides of the triangle of which the lengths are known are in this example the course and track. (*See* Fig. 18.)

Set one arm and pointer to 56°, 75 knots, and the other to 70°, 60 knots.

Turn the disc until both pointers are on a line parallel to the central arrow.

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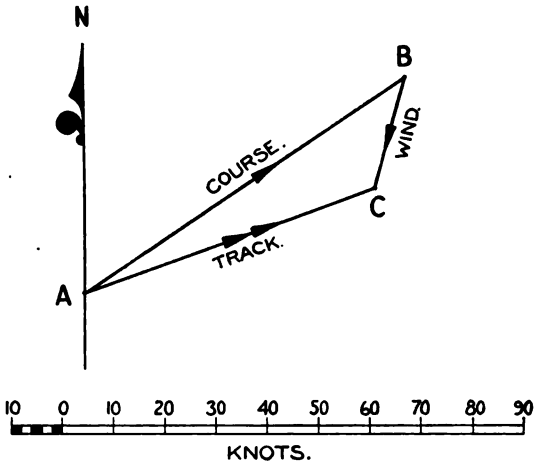


FIG. 17.—To find the velocity of the wind—by plotting.

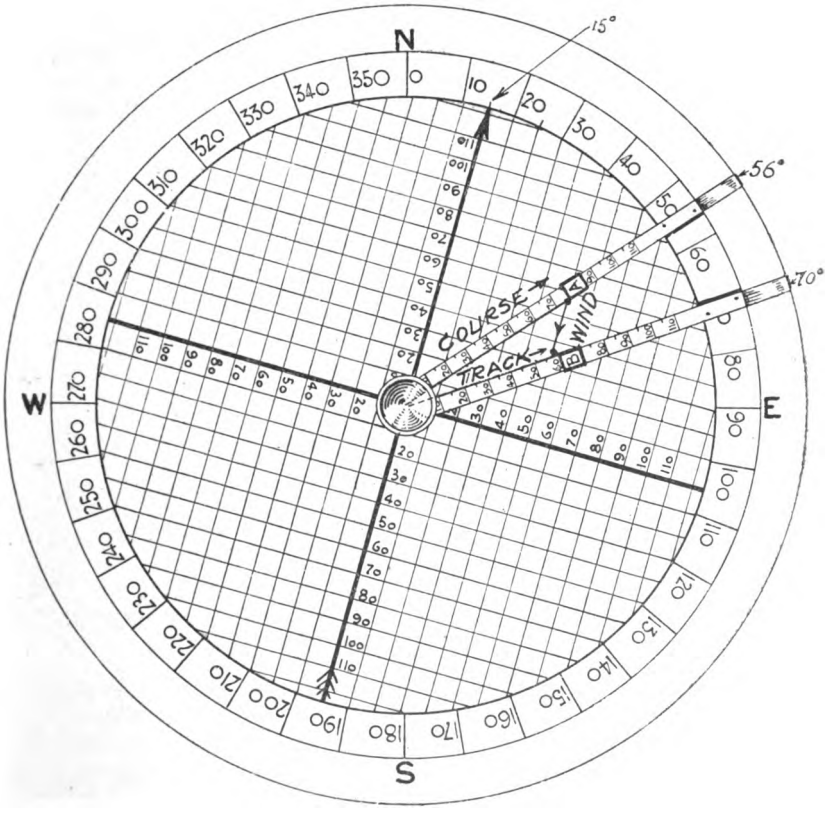


FIG. 18.—To find the velocity of the wind—by C.D.C.

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The distance between the pointers is 22 knots to scale, and, bearing in mind the rules above, it is seen that the wind blows from 15° ; then the velocity of the wind is 22 knots from 15° M.

### 5. To find the track and ground speed when the course, air speed and wind velocity are known

(i) *Example.*—Course 306° M., air speed 80 m.p.h., wind from 30° M., 20 m.p.h. Find the track and ground speed. (*See* Fig. 19.)

Draw NA to represent the magnetic meridian.

From A draw AB, 306° M. to represent 80 m.p.h.

From A draw AC, 30° M. to represent 20 m.p.h., noticing that it is necessary to draw the wind line *in the direction from which the wind blows* in order that the directions of the components may follow each other.

Join CB.

Then CB gives the track, 291° M., and the ground speed 80 m.p.h. (If the aeroplane flew from the point A along the course AB, its actual track would be on a line from A parallel to CB.)

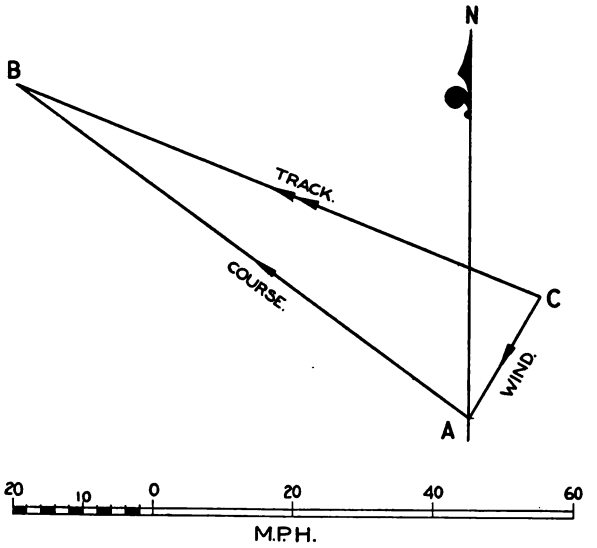


FIG. 19.—To find the track and ground speed—by plotting.

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(ii) *To solve by C.D.C.* (*See* Fig. 20.)

Set one arm and pointer to 306°, 80 m.p.h., and the other to 30°, 20 m.p.h. Turn the disc until both pointers are on a line parallel to the central arrow.

Then the direction of the track, reading from the head of the arrow, is 291°, and the ground speed is represented by the distance between the pointers, *i.e.*, 80 m.p.h.

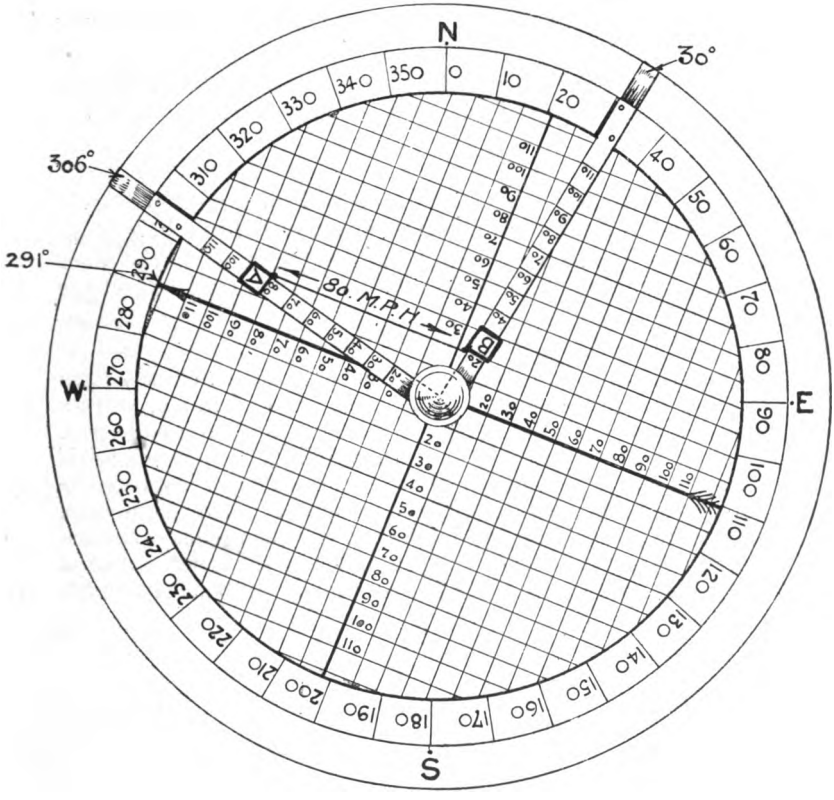


FIG. 20.—To find the track and ground speed—by C.D.C.

## 6. Time and distance scales

(i) The time and distance scale on the C.D.C. is a circular slide rule. It comprises an inner *time* scale and outer *distance* scale which can be rotated in relation to each other. Problems involving time, distance or speed can be readily solved by means of the time and distance scale.

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Three typical examples of problems are given below :—

(*a*) *Time.*—The ground speed of an aircraft is found to be 96 knots and the objective is 112 miles distant. Find the time taken to reach the objective.

Set 96 on the outer scale over 60 minutes on the inner scale and under 112 miles on the outer scale read 70 minutes on the inner scale.

Time, 1 hour 10 minutes.

(*b*) *Speed.*—It takes an aeroplane 72 minutes to cover 132 miles. What is the ground speed

Set 132 on the outer scale against 72 minutes on the inner scale, and against 60 minutes on the inner scale read 110 on the outer scale.

Ground speed, 110 m.p.h.

(*c*) *Distance.*—What distance will an aircraft cover in 1 hour 4 minutes at a ground speed of 134 m.p.h. ?

Set 134 on the outer scale against 60 minutes on the inner scale. Against 64 minutes on the inner scale read 143 on the outer scale.

Distance, 143 miles.

(ii) The time and distance scales being an elementary form of slide rule have several other uses. For example, statute miles may be easily converted to nautical miles and *vice versa.* Since 76 statute miles = 66 nautical miles, the instrument is set by moving the scales until 76 on one scale (for instance the outer scale) registers against 66 on the other. Any number of statute miles taken on the outer scale will then register against the equivalent number of nautical miles on the inner scale and *vice versa.* For example, 40 nautical miles = 46 statute miles.

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## CHAPTER VI.—FIXING POSITION

### 1. Fixing position by map reading

The accurate fixing of position at frequent intervals is of the greatest importance in air navigation. The simplest and most accurate method of obtaining a *fix*, i.e. of ascertaining the position of the aircraft, is to observe some recognised object on the ground, shown on the map, over which the aircraft passes. This is practically the only method possible to the pilot-navigator. When flying over the sea, in or above clouds, or in weather conditions which make accurate map reading impossible, one or more of the methods described below may be used.

### 2. Position lines

(i) If the bearing of an object be taken from an aircraft then the position of the aircraft must be somewhere on a line drawn from the object in the reciprocal direction. Such a line, on which the position of the aircraft is known to be, is called a *position line*. Thus, if by some means it is observed that a lightship bears 300° T. at a certain time from an aircraft, then the aircraft bears 300°−180°=120°T. from the lightship. Accordingly a position line may be drawn from the lightship on the chart in the direction 120° T. (Fig. 21.) It is most important that the exact time of the observation should be written against the position line. All position lines obtained by direct observation must be distinguished by drawing single arrowheads near each end.

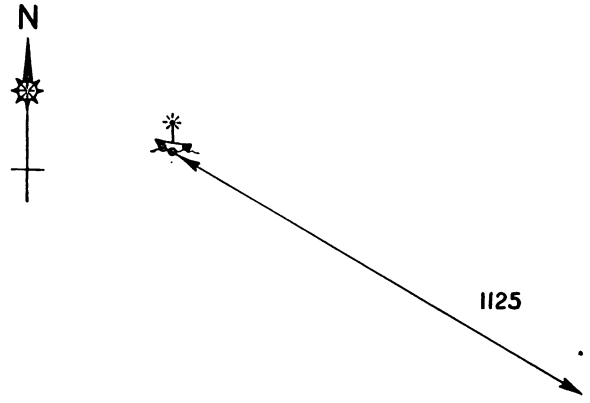


FIG. 21.—Position line.

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(ii) It frequently happens that only one position line can be obtained at a given moment, and although no fix can be obtained from this solitary observation, it may be used later when another observation of the same or a second object can be obtained.

(iii) Suppose the lighthouse in Fig. 22 bears 300° M. at 1125 hours and at 1135 hours it is possible to take an observation on another object. Provided that the track and ground speed are known it is possible to transfer the first position line. Let the track be 100° M. and the ground speed 96 miles per hour. At 1125 hours the position of the craft must have been somewhere on the position line such as A, B or C. In 10 minutes the craft will have travelled 16 miles

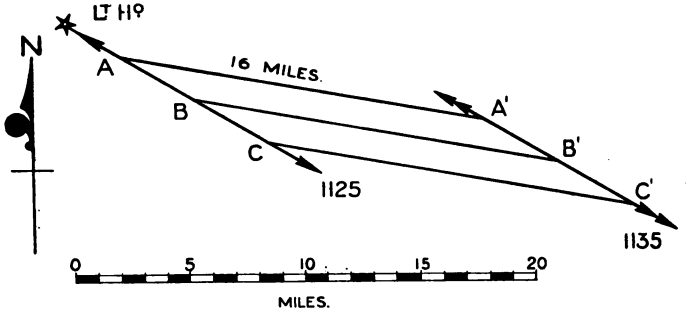


FIG. 22.—Transferring a position line.

in the direction 100° M. Then, if a line (for example AA') be drawn 16 miles to scale, 100° M., and through the point A' a line be drawn parallel to the first position line, it is clear that at 1135 hours the craft must be somewhere on the second line, which is called a *transferred position line.* Transferred position lines must always be distinguished by double arrow heads. The distance made good between the direct and transferred position lines is called the *run.* Since the track and ground speed are rarely known with absolute accuracy, position lines should not be transferred when it can be avoided, and no great reliance can be placed upon a position line which has been transferred for a considerable run.

### 3. Position lines by transits

When two objects on the Earth's surface appear to an observer to be in line with him they are said to be in transit and two objects in transit give a position line. Objects should not be selected too near the aircraft. Three miles may be taken as a suitable distance for the nearer object. The Greek letter $\phi$ is used to denote a transit in the air navigation log. Suppose Dover Castle and the Gull Lightship

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be observed in transit at 1220 hours. A position line should be drawn on the chart, as shown in Fig. 23. The entry in the log should be made as follows, the nearer object being named first.

" 1220 hours. GULL LIGHTSHIP $\phi$ DOVER CASTLE "

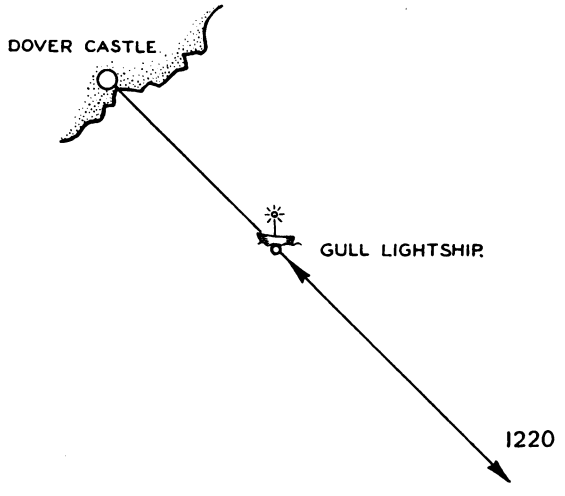


FIG. 23.—Position line by transit.

### 4. Position lines by bearing compass

The compass bearing of an object may be obtained by means of a bearing compass. The true bearing of an object is determined by applying to the compass bearing the deviation on the *course* of the craft at the instant of the observation and the variation for the year at the aircraft's estimated position, as described in chapter I, para. 7. The position line is drawn from the object in the direction of the reciprocal of the true bearing thus obtained. The bearings of two or more objects having been observed, a fix is obtained from the intersection of the reciprocal lines of bearing laid down from the objects on the map or chart. (*See* para. 7 below.)

### 5. Position lines by bearing plate

Bearings may be taken by means of a bearing plate when a bearing compass is not available. The inner graduated dial may either be kept set at zero, when the bearing observed will be relative to the aircraft's head, or, alternatively, the dial may be set to the true or magnetic course of the aircraft at the time of observation, when the bearing will be the

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true or magnetic bearing of the object respectively. Suppose in Fig. 24 the course of the aircraft is 290° M., the bearing plate is set to zero, and the angle observed from it is 90°. Then the magnetic bearing of the object is 290° plus 90°, which equals 380°, or 20°. On the other hand, if the graduated dial of the bearing plate is set to 290°, the magnetic course of the aircraft at the time of the observation, the magnetic bearing of 20° will be given by the instrument.

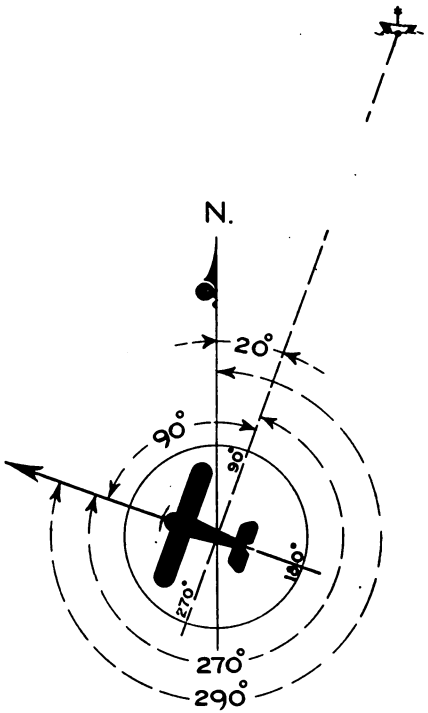


FIG. 24.—Position line observation by bearing plate.

When using the first of these two methods the reading of the bearing plate is always added to the course, 360° being subtracted when necessary. It will generally be found preferable to use the first method, as the second entails re-setting the bearing plate after every change of course.

### 6. Position lines by D.F. W/T.—Conversion angle

(i) Bearings obtained by Direction Finding W/T can be used as position lines. The various methods by which these bearings are found are described in chapter XVI.

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(ii) Bearings obtained by D.F. W/T are great circle bearings. As bearings from a station several hundred miles away may be used in air navigation, the plotting of lines of bearing obtained by W/T on a map or chart requires consideration. On all maps in use in the Royal Air Force, excluding any on Mercator's projection, a straight line on the map represents very nearly a great circle on the Earth. Hence, provided both the W/T station and the aircraft lie in the area shown on the map, W/T bearings may be plotted directly without appreciable error. If the bearing *of* the aircraft *from* a D.F. station or rotating beacon is found, the bearing is laid off on the map from the position of the W/T station, relative to the nearest meridian. If, on the other hand, a fixed coil or rotating loop system in the aircraft is used to obtain the bearing *of* a W/T station *from* the aircraft, a correction must be applied to the bearing, since the meridians of the aircraft and the W/T station are not parallel, but converge. The angle of convergence may be obtained from the difference between the grid deviations at the positions of the aircraft and the W/T station, since the grid lines are parallel throughout the map. In the northern hemisphere this correction should be added to bearings between 0° and 180° and subtracted from bearings between 180° and 360°. In the southern hemisphere, the converse applies. The reciprocal of the corrected bearing is then laid off from the W/T station relative to the meridian nearest to the W/T station.

(iii) It has already been explained that on a map or chart constructed on Mercator's projection, a straight line represents a rhumb line on the earth's surface. A line representing a great circle passing through two places on a Mercator's chart is a curve convex to the nearer pole, and lies always on the polar side of the rhumb line joining the places (Fig. 4). The angle between the great circle and the rhumb line is called the conversion angle.

(iv) The conversion angle may be calculated from the formula :—

$$\text{Conversion angle} = \tfrac{1}{2} \text{ d. Long.} \times \text{sin. Mid-lat.}$$

In practice it is sufficient to take the difference of longitude and the middle latitude (i.e. the latitude midway between the two positions) correct to the nearest degree. The approximate D.R. position must be known in order to find the conversion angle, but a considerable error in D.R. position will not seriously affect the calculation. A table of variations of the conversion angle for middle latitudes 49° to 59° is given in appendix VII. In this table the value of $\frac{1}{2}$ d. Long. is 1°. An example will make its use clear.

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*Example.*—Calculate the conversion angle when the D.R. position of the aircraft is 50° 21′ N., 06° 20′ W., and the position of the W/T station is 54° 14′ N., 15° 19′ W.

| | | |
|---|---|---|
| d. Long. (approximate) | = | 9° |
| ½ d. Long. | = | 4°·5 |
| Mid-lat. | = | 52° |

From the table the conversion angle for Mid-lat. 52° and ½ d. Long. 1°=47′. Multiply 47′ by 4·5. Then the conversion angle is 211′ or 3½°.

(v) The conversion angle may be worked out by C.D.C. by the following means :—

(*a*) Set the central arrow to zero.

(*b*) Place arm A to Mid-lat.

(*c*) Set pointer to ½ d. Long. × 10.

(*d*) The value of conversion angle × 10 may then be read off from the red line at right angles to the arrow by taking a line parallel to the arrow from pointer A.

The value given on the instrument is approximately 35, hence the conversion angle = 3·5°. The setting of the instrument is shown in Fig. 25.

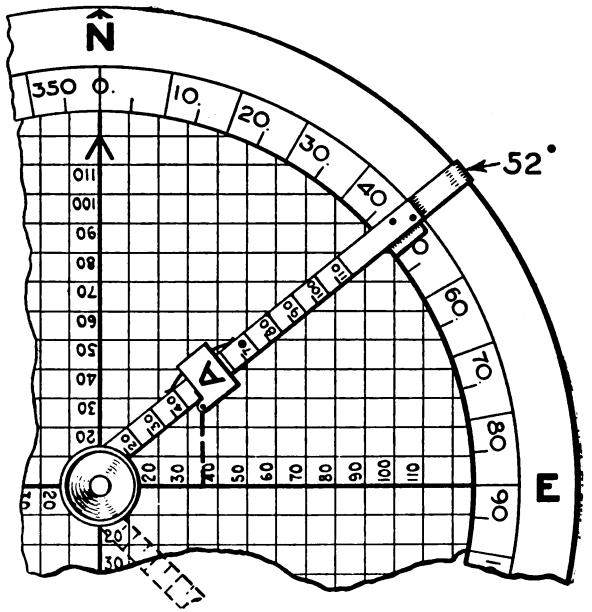


FIG. 25.—Calculation of conversion angle by C.D.C.

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(vi) When the conversion angle has been found, it must be correctly applied to the W/T bearing before a position line can be laid down. Consideration of Fig. 4 shows that to find the mercatorial bearing the following rule applies. In the northern hemisphere add the conversion angle to great circle bearings between 0° and 180° and subtract the conversion angle from great circle bearings between 180° and 360°. In the southern hemisphere, the converse applies. If the bearing *of* the aircraft *from* a W/T station is obtained, apply the conversion angle and lay off the mercatorial bearing on the chart from the position of the W/T station. If the bearing *of* a W/T station *from* the aircraft is obtained, apply the conversion angle to the great circle bearing, obeying the rule given above, and lay off from the W/T station the reciprocal of the mercatorial bearing thus obtained.

The portion of the bearing drawn on the chart in the neighbourhood of the D.R. position will form a reliable position line. It is quite feasible to obtain position lines from stations as far distant as 1,200 miles without sensible error.

**7. Fixes by intersection of position lines**

(i) When two or more position lines intersect, the point of intersection constitutes a *fix*. When one or more of the position lines have been transferred, the resulting fix is known as a *running fix*.

(ii) In order to obtain a reliable fix from position lines, the following precautions should be observed :—

(*a*) Before taking bearings, the observer should be quite sure as to what objects he proposes to use, and should make certain that they are marked on the map or chart.

(*b*) The objects on which bearings are taken should be selected so that the position lines cut at an angle of about 90° whenever possible. No reliance can be placed on a fix when the position lines meet at an angle of less than 30°.

(*c*) When any choice exists, bearings should be taken on objects near the aircraft in preference to those a great distance away, because any error in bearing of a near object has less effect on the accuracy of a fix than the same error in the bearing of a more distant object when the position lines are plotted.

(*d*) Bearings which are used for fixing positions should be taken as nearly simultaneously as possible : position lines should not be transferred when it is possible to avoid it.

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(*e*) In taking nearly simultaneous bearings of two objects, the object, the bearing of which is changing most rapidly, should be observed last. The most favourable conditions are when the first object is nearly ahead or astern and the second nearly abeam.

(*f*) When possible, a third position line should be used as a check. The three lines will usually not pass exactly through one point, but will form a small triangle known as a " cocked hat ". If this is small, the position of the aircraft can be taken as inside it, but if it is large, the work on the chart should be carefully revised and if a better result is not obtained after revision, it should be disregarded.

(*g*) The exact time of taking a bearing should be observed and recorded in the log together with other particulars of the bearing.

(*h*) To distinguish a fix from any other intersection of lines on the map or chart, a small circle should be drawn round it and the time of the fix written nearby.

(*i*) When bearings are taken by a compass, the deviation to be used to correct the bearings is that on the *course* of the aircraft at the moment of observation. Thus it is essential to note the course when bearings are taken.

(iii) When laying off lines of bearing on a map or chart, it must be remembered that both visual and W/T bearings are arcs of great circles. Although it is necessary to convert W/T bearings to mercatorial bearings before laying them off on a map or chart on Mercator's projection, position lines obtained visually are normally so short that they may be plotted as straight lines on any projection without sensible error.

(iv) *Example of a fix by simultaneous bearings.* (*See* Fig. 26).—At 1035 hours the bearing of a lighthouse (A) is found to be 085° by bearing compass, and at the same time the bearing of a church (B) is 348°. The course of the aircraft, as indicated by the bearing compass, is 270°, and the deviation of the compass on this course is found from the deviation card to be −3°. The variation is 12° W. The compass bearings obtained are converted to true bearings as follows :—

| *Comp.* | *Devn.* | *Mag.* | *Varn.* | *True.* |
|---|---|---|---|---|
| 085° | −3° | 082° | −12° | 070° |
| 348° | −3° | 345° | −12° | 333° |

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Thus the true bearings are 070° and 333°, so that the position lines are laid down on the chart in the directions 250° T. and 153° T. from A and B respectively.

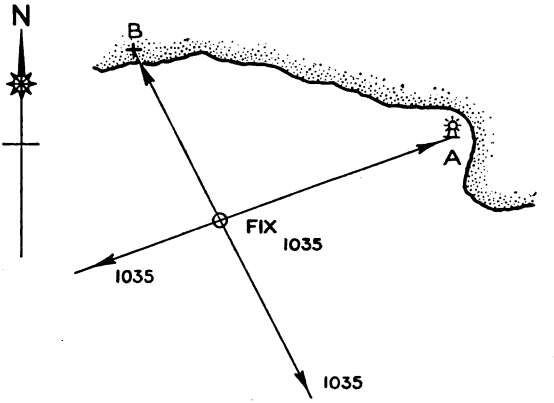


FIG. 26.—Fix by simultaneous bearings.

(v) *Example of a running fix by bearings of two objects at different times.* (*See* Fig. 27).

1115 hrs. Bearing of A, 008° T.
1125 hrs. Bearing of B, 312° T.
Track 080° T. Ground speed 120 knots.

The 1115 position line is laid down on the chart in the direction 188° T. from A. The 1125 position line is laid down in the direction 132° T. from B. In the interval of 10 minutes, the aircraft has made good 20 nautical miles, 080° T. From the point C where the first position line cuts

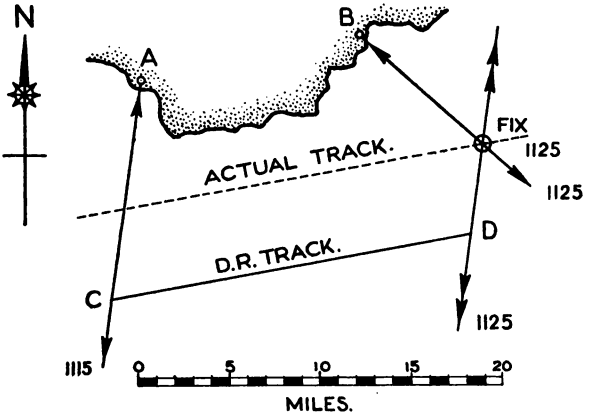


FIG. 27.—Running fix.



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the D.R. track, a distance of 20 miles to scale is measured along the D.R. track. Through the point so obtained (D), a line parallel to the 1115 position line is drawn. This is the transferred position line, and its intersection with the 1125 position line gives the fix at 1125 hours. A line drawn through the fix parallel to the D.R. track is the actual track.

It should be noted that exactly the same result would be obtained if the point C was taken anywhere on the first position line, and if C D was drawn 20 miles to scale in a direction 080° T. Normally, however, the D.R. track is already drawn on the chart and it is therefore convenient to measure the distance C D along it.

If three position lines are observed, the first two are transferred to the time of the third and a "*cocked hat*" is formed.

(vi) *Example of a running fix from successive bearings on the same object.*—The method is exactly the same as in the last example, and is sufficiently explained by Fig. 28, which shows a fix obtained by three successive bearings of an object.

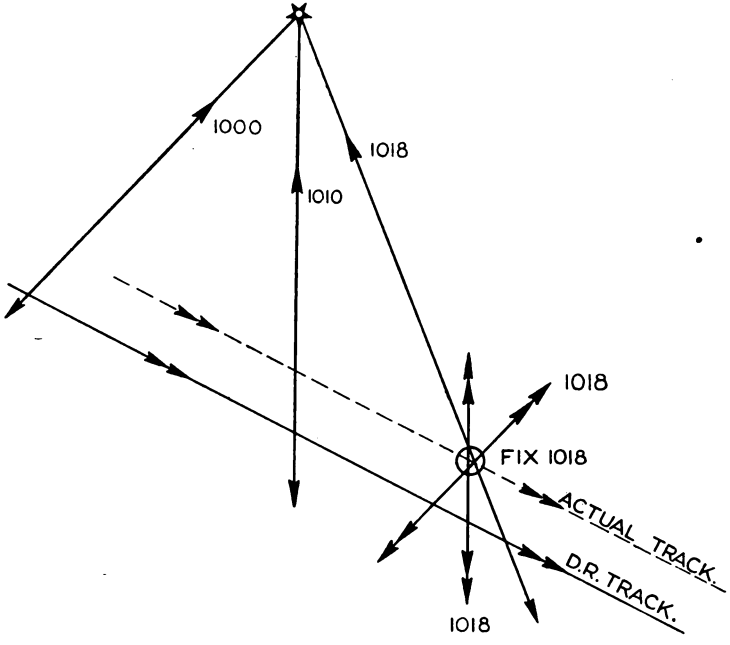


FIG. 28.—Fix by successive bearings of the same object.

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## CHAPTER VII.—DETERMINATION OF DRIFT, TRACK AND GROUND SPEED

### 1. Dead reckoning

The term *dead reckoning* is defined as the process of calculating the track and ground speed of an aircraft. The abbreviation " D.R." is always used. *D.R. track* and *D.R. position* are respectively the track and position arrived at by such calculation.

Both track and ground speed can be found, independently or together, by direct measurement. Since course and air speed are always known, then, if the wind velocity is given, the track and ground speed can be calculated from the triangle of velocities. Conversely, if the track and ground speed are known, the wind velocity can be calculated. Drift, being the angle between the course and the track, is an important factor in the solution of the triangle of velocities.

Measurement and calculation of drift, track, ground speed and wind velocity are the essence of D.R. navigation.

### 2. Methods of finding the drift

(i) *By the angular difference between the track and the course.*—When the track is known accurately, as it might be from two or more fixes, the drift may be found by taking the angular difference between the course and the track. Thus, if the course is 200° M. and the track 184° M., it is clear that the drift is 16° to port (written 16° P.).

(ii) *By bearing compass.*—Drift may be obtained by observing the track by back bearing of a fixed object or sea marker (*see* para. 3 (ii) below) and taking the angular difference between the track thus found and the course.

(iii) *By bearing plate.*—The use of this instrument is described in chapter XI, para. 13.

(iv) *By course setting bomb sight.*—The use of this instrument is described in chapter XI, para. 12.

(v) *By tail drift sight.*—The use of this instrument is described in A.P. 1275, Manual of Instrument Equipment for Aircraft, Vol. I, section 9, chapter I.

(vi) *By drift markings.*—This method is normally only used by the pilot-navigator, and is described in chapter XI, para. 15. It should only be resorted to when instruments cannot be used.



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**3. Methods of finding the track**

(i) *From two fixes.*—If two fixes have been plotted on a map or chart, the track can be laid down by a straight line joining them and measured by means of a protractor.

(ii) *By back bearings.*—If an aircraft flies directly over a fixed point and is kept on a steady course, it is clear that a bearing taken of this point from the aircraft will be the reciprocal of the track being made good. The bearing should be taken by bearing compass or bearing plate when the object is well astern. The mean of several readings should be taken. To correct a bearing taken by bearing compass the deviation on the *course* of the aircraft must be applied.

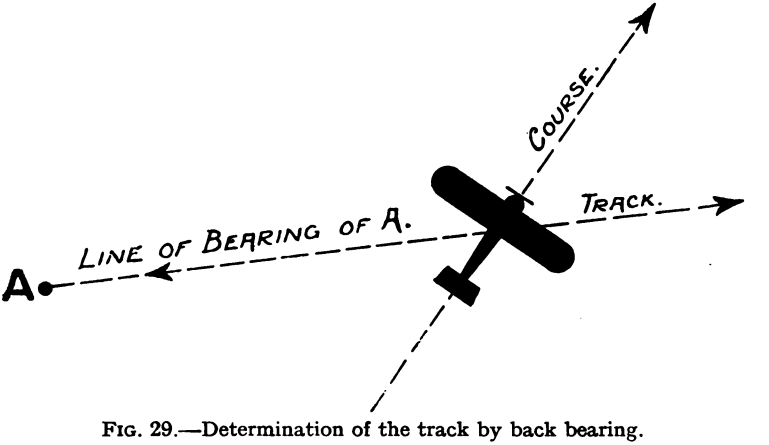


FIG. 29.—Determination of the track by back bearing.

When flying over the sea, sea markers, flares and smoke floats may be used to obtain the track by this method.

(iii) *From an observation of drift.*—The track can always be found from an observation of drift, since drift is the angle between the course and the track. Thus, if the drift is found to be 5° S. and the course steered is 283° M., the track made good must be 288° M.

(iv) *By three successive bearings of one object.*—This method will give the track with a reasonable degree of accuracy, but normally it should only be used when one object alone is available. The bearings may be either visual or W/T. Three successive bearings are obtained, and the exact time between the bearings noted. The problem may be worked on the C.D.C. as shown by the following example :—

Suppose that the bearings obtained are 7°, 73° and 111°. The 1st bearing, 7°, is set on one arm A of the C.D.C. (*see* Fig. 30), the 2nd bearing is set against the arrow on the centre disc of the C.D.C. and the 3rd bearing is set on the other arm.

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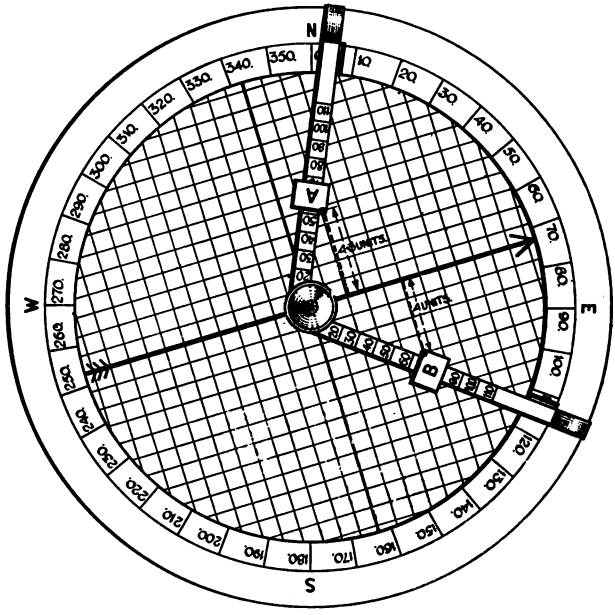


FIG. 30.—Determination of the track from three bearings of one object.

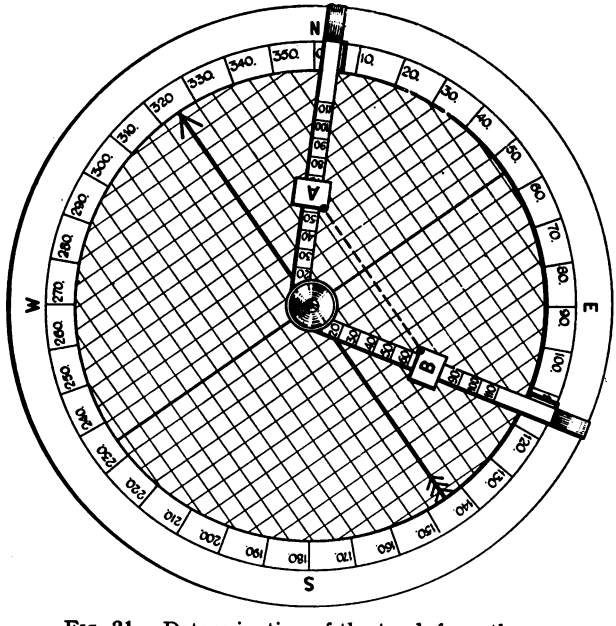


FIG. 31.—Determination of the track from three bearings of one object.

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If the interval of time between the 1st and 2nd bearings is 4 m. 50 s. and that between the 2nd and 3rd is 4 m., slide pointer A so that its perpendicular distance from the central arrow is 4·8 units and pointer B so that its perpendicular distance from the central arrow is 4 units (*see* Fig. 30). Revolve the centre disc until the arrow lies parallel to pointers A and B (*see* Fig. 31). The arrow will give the direction of the track or its reciprocal. The direction of the track will be evident from commonsense principles : in this problem it is 325°.

**4. Methods of finding the ground speed**

(i) *By the time and distance between two fixes.*—If two fixes are obtained, the ground speed can be calculated very quickly by measuring the distance and the time interval between them, and using the time and distance scale on the C.D.C. as described in chapter V, para. 6. This is the most reliable method and should be used whenever possible.

(ii) *By bearing plate.*—This method is described in chapter XI, para. 13.

(iii) *By course setting bomb sight.*—This method is described in chapter XI, para. 12.

**5. Keeping D.R. during frequent changes of course.**

During operations it may be necessary to alter course frequently, and keeping the dead reckoning may be difficult if the new track and ground speed have to be calculated consequent upon every change of course. When possible the reckoning should be kept by noting the times of alterations and the new courses in the log. Successive courses and " air distances " are then plotted on the map or chart, forming a record of the " air positions " of the aircraft. To find the geographical position at any given time, lay off from the corresponding air position the wind for the total time since leaving the starting point. The following example illustrates the method :—

1000 hours Fix at A. S/C 090° M. Air speed 120 knots.
1005 ,, A/C 120° M.
1009 ,, A/C 106° M.
1011 ,, A/C 170° M.
1015 ,, A/C 182° M.
1026 ,, A/C 220° M.
Wind from 120° T., 25 knots.

It is required to find the position of the aircraft at 1030 hours.

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The successive positions of the aircraft are plotted, disregarding the wind, i.e., the first course is laid off from A at 090° M. for 10 miles, the second 120° M. for 8 miles, and so on (*see* Fig. 32). Thus the position B is arrived at, which is the air position at 1030 hours. Between 1000 hours and 1030 hours, however, the wind has carried the aircraft in the direction 300° T. a distance of 12·5 miles. By laying off a wind line down wind from B for 12·5 miles the D.R. position for 1030 hours (C) is obtained.

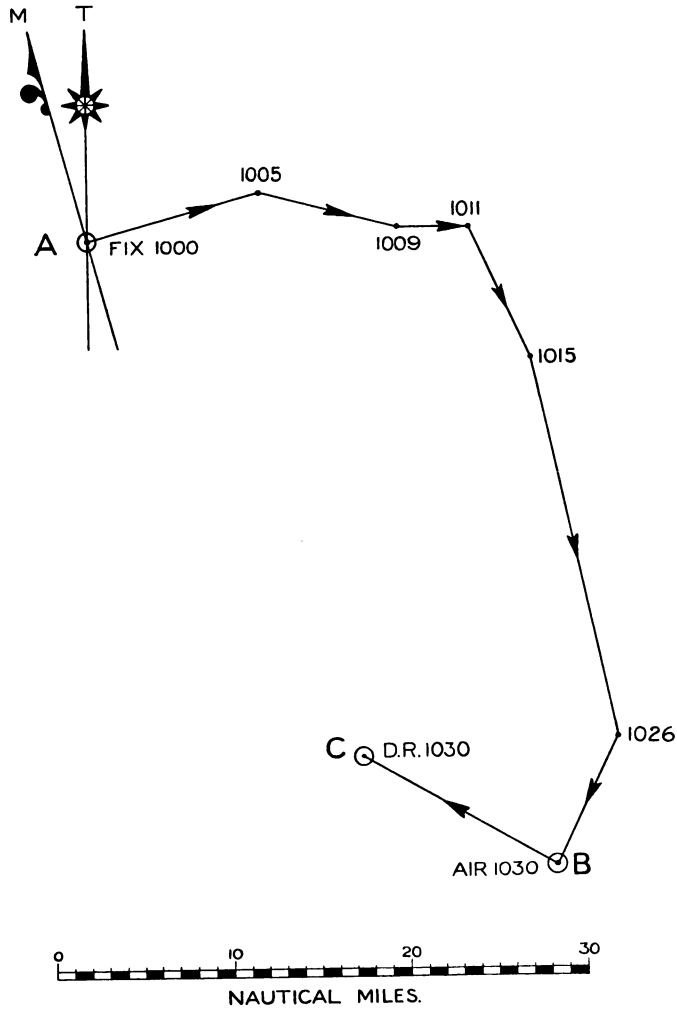


FIG. 32.—Method of keeping D.R. during frequent changes of course.

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## CHAPTER VIII.—METHODS OF FINDING THE WIND VELOCITY

### 1. Estimation of wind velocity

(i) It is often possible when flying at a low height, particularly over the sea, to estimate the value of the wind velocity at the surface. Over the land, the direction in which smoke is drifting and its approximate speed can be gauged. Over the sea, the surface of the water gives an indication of the wind velocity. When the wind reaches a speed of 10–12 knots, "*wind lanes*," having the appearance of light-coloured parallel lines, lying up and down wind, may be seen, and their direction can be measured by means of a bearing compass. Scattered " white caps " are seen when the wind speed is 15–18 knots, and at about 20 knots there is a general appearance of white caps.

(ii) It must be remembered that wind velocity changes with height, as explained in chapter XVII, para. 7. An estimate of the surface wind is therefore of no practical use unless the approximate amount of the variation with height is known. (*See* chapter IX, para. 4.) When flying at a low height an observed change in the speed or direction of the surface wind may be useful as indicating a corresponding change of the wind at the height at which the aircraft is flying.

### 2. To find wind velocity when track and ground speed are known

(i) When the track and ground speed have been found by any of the methods described in chapter VII, the wind velocity can be determined by means of the triangle of velocities, either by plotting or by the C.D.C., as described in chapter V, para. 4. If the course setting bomb sight is used for determining the track and ground speed, the wind velocity can be found directly from the instrument. (*See* chapter XI, para. 12 (viii).)

(ii) It may often be more convenient to plot the triangle of velocities on the map or chart, as in the following example :—

*Example.*—At 1027 hours an aircraft was over Odiham Church (Grid reference (w)Q1870). (*See* Plate II at end of book.) At 1039 hours the aircraft was over Bishops Waltham station ((v)U9937). Course steered 233° M., air speed 105 m.p.h. Variation 12° W. To find the wind velocity :—

Draw a line from Odiham Church to Bishops Waltham station. This is the actual run made good in 12 minutes. From Odiham Church draw a line in the direction of the

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course (221° T.) and on it mark a point A, 21 miles from the departure point. This represents the "*air position*" of the aircraft 12 minutes after leaving Odiham, i.e., the position at which the aircraft would have arrived if there were no wind.

Join point A to Bishops Waltham station. This line gives the direction of the wind and the distance it has blown the aircraft in 12 minutes. Hence the wind velocity is 339° T., 25 m.p.h.

### 3. To find wind velocity from drift on two or more courses

(i) Any constant course is steered and the angle of drift observed. The course is altered by an amount which should not be less than 50° and the drift observed on the second course. Whenever possible, a further alteration of course should be made and a third drift obtained. The wind is then found by plotting as in the following example :—

*Example.*—Course 270° T., drift 11° S.
Course 215° T., drift 9° S.
Course 152° T., drift 14° P.
Air speed 100 m.p.h.

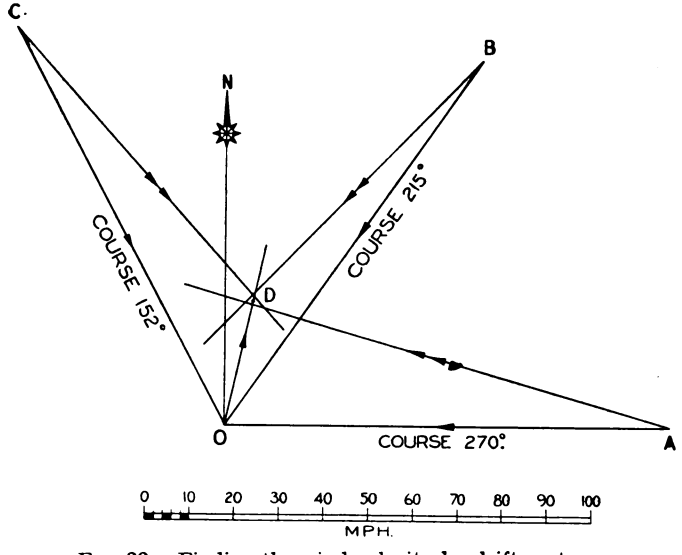


FIG. 33.—Finding the wind velocity by drift on two or more courses.

Choose any convenient point O and draw the true meridian ON. (*See* Fig. 33.) From O lay off OA, OB and OC in the directions of the reciprocals of the courses (i.e., 90° T., 35° T.

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and 332° T.) to represent the air speed (100 m.p.h.) to a suitable scale. From the points A, B and C draw lines making angles of 11°, 9° and 14° respectively with the courses, as shown. Note that starboard drift is laid off to the right of the course and port drift to the left. The three track lines will rarely meet at a point, but will form a small triangle called a "*cocked hat*". Mark the centre of this "cocked hat" D, and join it to O: then OD represents the wind velocity, in this example 192° T., 29 m.p.h.

The direction of the wind should never be in doubt if it is remembered that "*the wind always blows from the course to the track.*"

(ii) In the example illustrated above, the drift was observed on three courses. In practice it often happens that time only allows of one alteration of course. In this case the "wind point" (D in Fig. 33) will be the intersection of the two track lines. To obtain the most accurate results, the courses should be chosen so that the track lines cross as nearly as possible at right angles.

(iii) If a course setting bomb sight is used for measuring the drift, the problem can be solved by means of the bomb sight without the necessity of plotting the drifts on paper. This is the "three course" method of obtaining wind velocity, and is described in chapter XI, para. 12 (vii). A mechanical solution can also be obtained by means of the course and speed calculator. (*See* chapter XI, para. 8.)

**4. The 90-degree method**

(i) For this method it is essential that the approximate direction of the wind should be known. The pilot flies as nearly up-wind as possible, altering course until zero drift is observed. The course of the aircraft then gives the direction from which the wind is blowing. Course is altered by 90°, either to port or starboard, and the drift measured as accurately as possible. Then, by using the table shown in appendix IX, the wind velocity is obtained with fair accuracy. Alternatively, the C.D.C. may be used. For example, by flying up-wind the direction is found to be 300° M. The aircraft is turned 90° to starboard and steered on 030° M., and the drift is found to be 14° to starboard. Air speed 105 m.p.h. To find the wind velocity:—

(*a*) Set arm A at 300°, direction of the wind.

(*b*) Set arm and pointer B to the second course steered and air speed, 30°, 105 m.p.h.

(*c*) Set arrow to track made good (30° + 14° = 44°).

(*d*) Slide pointer A so that AB is parallel to the arrow.

(*e*) Pointer A shows the speed of the wind (26 m.p.h.) and the wind velocity is thus 300° M., 26 m.p.h.

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(ii) The course setting bomb sight may be used for finding the wind velocity by this method. The procedure is described in chapter XI, para. 12 (vi).

### 5. The drift and bearing method

This method is carried out as follows :—

The aircraft is flown over a selected object on a steady course and air speed. After a suitable interval of time the back bearing of this point of departure is observed and the course is altered by not less than 50°. The time of alteration of course is noted. After a further interval of time a second bearing of the point of departure is taken, the time being again noted.

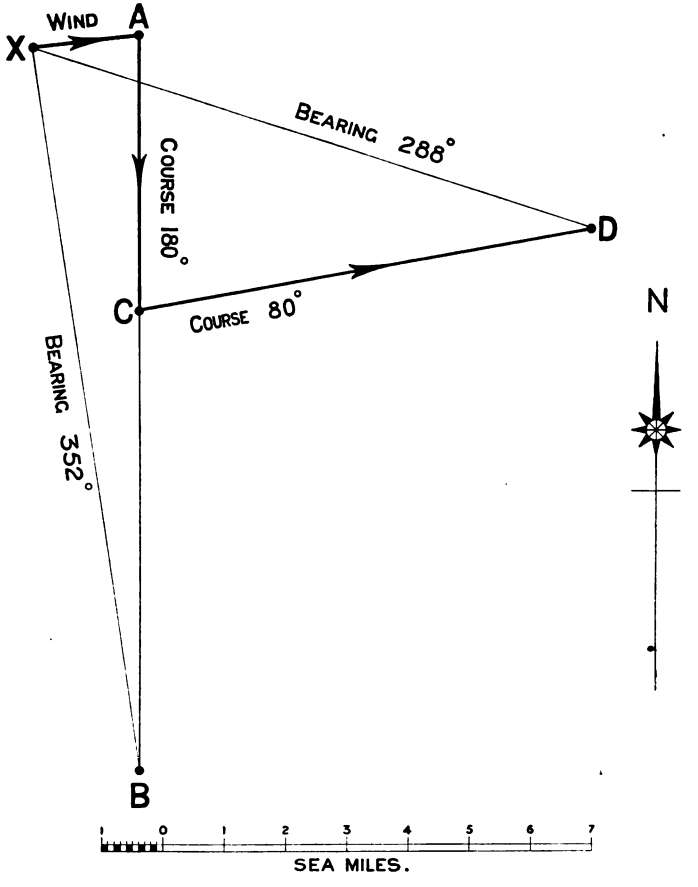


FIG. 34.—Drift and bearing method of wind finding.

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*Example.*—An aircraft whose air speed is 90 knots is flown over a point A (Fig. 34) on a course of 180° T. A back bearing of A is taken and found to be 352° T. After 3 minutes, course is altered to 080° T. After 5 minutes on the second course the bearing of A is found to be 288° T.

The wind velocity is found by plotting as follows :—

From A lay off AB in the direction of the first course, i.e., 180°. Make AB = the air distance run in 8 minutes = 12 miles.

Lay back from B the departure bearing 352°.

On AB mark the point C so that AC = the air distance run in 3 minutes = $4\frac{1}{2}$ miles.

From C lay off CD in the direction of the second course, i.e., 080°. Make CD = air distance run in 5 minutes = $7\frac{1}{2}$ miles.

Lay back from D the second bearing 288°.

The first and second bearings intersect at X. The line XA represents, in direction and length, the direction and speed of the wind for 8 minutes: 1·7 miles from 263° T.

The wind is therefore 13 knots from 263° T.

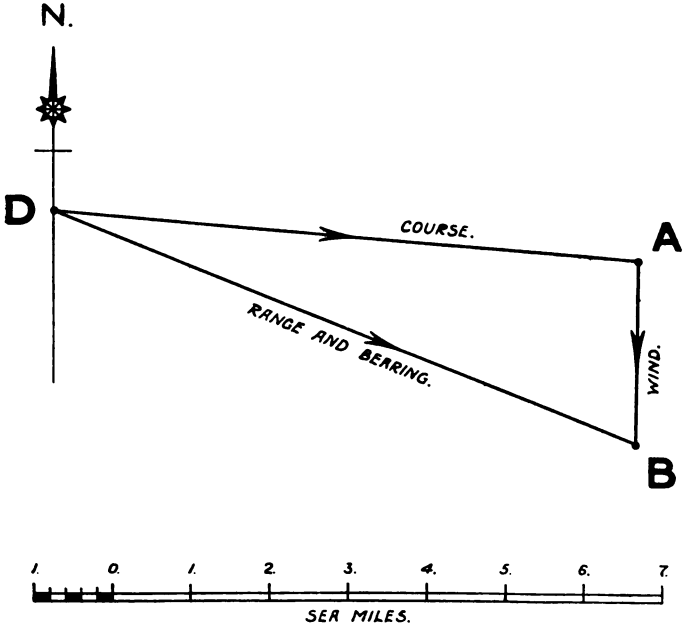


FIG. 35.—Range and bearing method of wind finding.

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### 6. The range and bearing method

The pilot steers over a selected object and maintains a constant course and air speed. After a suitable interval of time the bearing and range of the object are observed and the position of the aircraft is plotted on the map or chart. The wind velocity can then be found as described in para. 2 (ii) above.

*Example.*—An aircraft flies over a point D (Fig. 35) steering 095° T. at air speed 90 knots. After 5 minutes the bearing and range of D are found to be 292° T., 8 miles.

From D draw DB in direction 112° T. (reciprocal of the bearing of the object, i.e., the aircraft's track) 8 miles to scale.

Then B is the position of the aircraft.

Draw DA in direction 95° T., $7\frac{1}{2}$ miles. (Course and air speed for 5 minutes.)

Then AB represents the wind for 5 minutes.

From the diagram, AB = 2·35 miles and the wind velocity is therefore 002° T., 28 knots.

### 7. The reciprocal track method

(i) This method is also called the "*quick turn*" method. The principle involved may be expressed thus :—

If an aircraft, maintaining a steady course and air speed, passes over an object and the angle of drift is observed, the course back to the object may be found by doubling the observed drift and applying it to the reciprocal of the outward course.

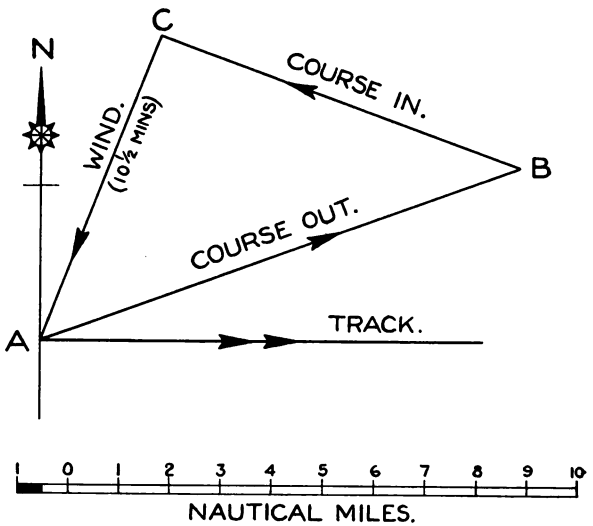


FIG. 36.—Reciprocal track method of wind finding.

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Consider a concrete case :—An aircraft passes over the point A (Fig. 36) steering 070° at 100 knots. The back bearing of A is found to be 270°, and the track is therefore 090° and the drift 20° S. At the end of a suitable interval of time (say 6 minutes) the course is altered to 290° (the reciprocal of 070° plus twice 20°) in order to bring the aircraft back over A. Suppose that the aircraft arrives back over A after a further 4½ minutes.

The problem is solved by plotting as follows :—

From A lay off AB, 070°, 10 miles to represent the first course for 6 minutes. From B draw BC, 290°, 7½ miles to represent the second course for 4½ minutes. Had there been no wind the aircraft would have arrived at C ; thus CA represents the wind for 10½ minutes. The wind velocity is therefore 021°, 37 knots.

(ii) The problem can be solved by means of the C.D.C. as follows. Set arm A to the first course and arm B to the first course plus or minus twice the angle of drift. (Plus for starboard drift, minus for port drift.) Set pointer A to the air distance on the first course (multiplied by 10) and pointer B to the air distance on the second course (multiplied by 10). Revolve the central disc until the arrow lies parallel to pointers A and B. The arrow will give the direction of the wind, which blows from A to B. The distance AB gives the wind for the total time.

In the example, set arm and pointer A to 70°, 100 miles, and arm and pointer B to 110°, 75 miles. The wind direction will be found to be 21° and the distance AB 65 miles. Set 65 on the outer of the time and distance scales to 105 on the inner, and read the wind velocity (37 knots) on the outer scale opposite 60 on the inner.

(iii) The chief merit of this method is that the observer knows that his calculations are reasonably accurate if the aircraft passes over, or nearly over, the departure point on its return.

The aircraft will only pass directly over the departure point if the radius of the turning circle is nil. Consequently the turn should be carried out as quickly as possible.

### 8. The reciprocal course method

(i) In this method, the aircraft is flown on a steady course over a selected object, and the course is maintained for a definite time, e.g., three or five minutes, after passing over the object. A 180° turn is now carried out and the reciprocal course flown for the same time. At the end of the second course the aircraft is turned towards the object, which it will always approach up-wind ; consequently, the course of the

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aircraft towards the starting point gives the direction of the wind. The time taken from the second turning point to the object is measured with a stop-watch: from this time the wind speed is found by reference to the tables given in appendix X.

(ii) The 180° turn should be begun a few seconds before the end of the first 3- or 5-minute course, and the turn completed as quickly as possible. Owing to the fact that the compass is disturbed by the turn and will not settle down again for some time, a cloud or mark on the ground directly behind the aircraft should be selected immediately before the turn is begun, and the aircraft turned on that mark. The necessity of making a large turn on to the final run to the starting point can be avoided if the first course is as nearly down-wind as possible.

(iii) The principle of this method is as follows:—

In still air, the aircraft would arrive back over the starting point at the end of the second course. The distance from the starting point at the end of the second course is therefore the distance that the wind has blown the aircraft in 10 minutes, if 5-minute courses are flown (6 minutes if 3-minute courses are flown). Thus, if the wind speed is $W$ m.p.h. this distance is $\frac{W \times 10}{60} = \frac{W}{6}$ miles. Since the aircraft approaches the starting point up-wind, its ground speed is $(A - W)$ m.p.h., where $A$ m.p.h. is the air speed. The time taken to reach the starting point is therefore $\frac{W}{6\,(A - W)}$ hours, or $\frac{600\ W}{(A - W)}$ seconds. If we call this time $T$ seconds, then, for 5-minute courses:—

$$\frac{600\ W}{A - W} = T$$

$$\text{from which } W = \frac{AT}{600 + T}$$

For example, if the air speed is 140 m.p.h. and the time measured is 100 seconds, the wind speed must be $\frac{140 \times 100}{700}$ or 20 m.p.h.

(iv) This method will only give accurate results if the radius of the turning circle of the aircraft is small.

### 9. The smoke cloud method

(i) This method involves the use of an artificial cloud such as may be produced by stannic chloride or a smoke puff cartridge. The aircraft flies over a selected object on any

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course and the smoke cloud is released and a stop watch started when the aircraft is exactly over the object. The aircraft is then turned slowly, a steady air speed being maintained, and the smoke cloud and the object kept in view. After approximately 2 minutes (3 if the wind appears to be light) the aircraft is flown through the cloud and straight towards the ground object. The times of passing through the cloud and over the object are noted, as is also the course steered. The latter gives the direction of the wind while its speed can be found by means of the time and distance scale on the C.D.C. as follows :—

Set the total time (i.e., the time from the moment of releasing the smoke cloud to the moment of passing again over the ground object) on the inner scale against the time from the cloud to the object on the outer scale. Then against the air speed on the inner scale read the wind speed on the outer scale.

(ii) The principle of this method is as follows :—

Suppose that the time interval between leaving the starting point and passing through the cloud is $T_c$ seconds ($\frac{T_c}{3600}$ hours), and that the total time taken to get back over the starting point is $T_o$ seconds. When the aircraft passes through the cloud, the latter has drifted down-wind a distance of $\frac{W\,T_c}{3600}$ miles, where $W$ m.p.h. is the wind speed. Since the aircraft approaches the ground object up-wind, its ground speed is $(A - W)$ m.p.h. where $A$ m.p.h. is the air speed, and it covers the distance in $(T_o - T_c)$ seconds, or $\frac{T_o - T_c}{3600}$ hours.

$$\text{Now ground speed in m.p.h.} = \frac{\text{distance in miles.}}{\text{time in hours.}}$$

$$\text{Hence } \frac{W\,T_c}{3600} \div \frac{T_o - T_c}{3600} = A - W$$

$$\text{from which } \frac{W}{A} = \frac{(T_o - T_c)}{T_o}, \text{ or } W = \frac{A\,(T_o - T_c)}{T_o}$$

For example, if the total time $T_o$ is 160 seconds, and the time from the cloud to the object is 32 seconds, the air speed being 120 m.p.h., then the wind speed is

$$\frac{120 \times 32}{160} \text{ or } 24 \text{ m.p.h.}$$



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### 10. Wind finding over the sea

The methods described above may be used for finding the wind velocity when flying over the sea as well as over the land. Where the method depends on observations of a fixed object, a sea marker or navigation smoke float may be used.

In addition, provided that its course and speed are taken into consideration, a moving ship will serve in place of a stationary object, as explained in the next paragraph.

### 11. Relative wind

(i) When the wind velocity is determined by means of observations of a moving ship, the methods are carried out in exactly the same way as with a fixed object, though the wind found is not the true wind, but is a velocity compounded of the velocities of the ship and the true wind, and is called the *relative wind.*

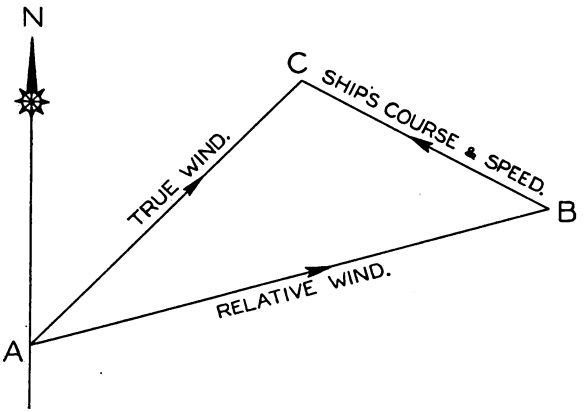


FIG. 37.—Relative wind.

(ii) The true wind may readily be found by means of the triangle of velocities, either by plotting or by the use of the C.D.C. The plotting is carried out as follows :—

> From any point A (*see* Fig. 37) lay off the relative wind AB (down-wind). From B lay off the ship's course and speed BC. Then AC represents the true wind velocity. Note that "*the wind always blows towards the ship.*"

(iii) The plotting is normally done as part of the problem being solved. For example, Fig. 38 illustrates wind finding by the reciprocal track method using the same example as Fig. 36, but assuming as datum a moving ship whose velocity is 315°, 20 knots. On the outward course a steady bearing of 090°

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from the ship is maintained. It should be noted that the " track " of 090° laid off on the plot is the track relative to the ship, and must not be confused with the true track over the sea. The inward course is 290° as before, and the aircraft arrives back over the ship $10\frac{1}{2}$ minutes after leaving it. CA therefore represents the relative wind for $10\frac{1}{2}$ minutes. To find the true wind, lay off AD to represent the ship's course and speed for $10\frac{1}{2}$ minutes (i.e., 315°, 3·5 miles). Then CD represents the true wind for $10\frac{1}{2}$ minutes, which is found to be 052°, 6 miles. The wind velocity is, therefore, 052°, 34 knots.

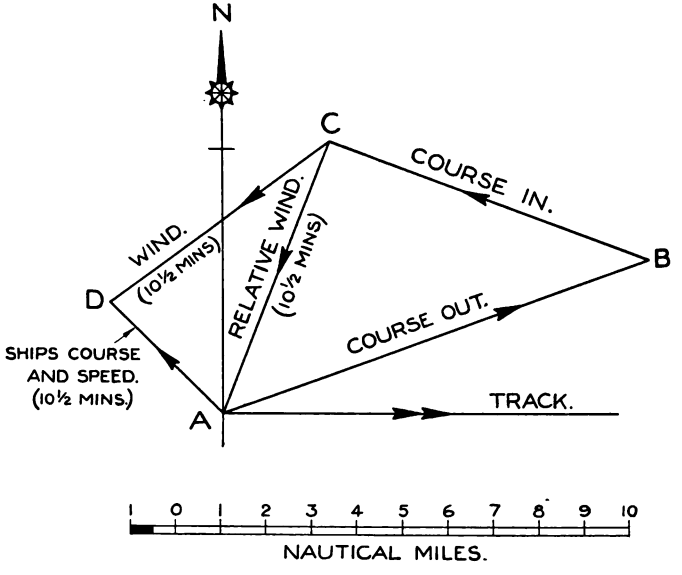


FIG. 38.—Reciprocal track method—moving datum.

(iv) To find the true wind by C.D.C., set arm and pointer A to the relative wind velocity, and arm and pointer B to the ship's course and speed. Rotate the central disc until the arrow is parallel to the pointers A and B, and read off the direction of the true wind at the arrow. The length of AB is the wind speed. (It should be remembered that the direction of the wind is always that *from* which it is blowing.)



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## CHAPTER IX.—PRACTICAL AIR NAVIGATION

### 1. The navigation log

(i) The navigation log (Figs. 39 and 40) is a record which is kept, step by step, of the navigational work done during a flight. A log should always be kept, as the record it contains will often prove useful afterwards. No unnecessary information should appear in the log, but that which is entered must be clear and accurate: the amount of information recorded will vary with circumstances. The most important entries include courses steered, times of changes of course, changes of wind observed or calculated, fixes, ground speeds and tracks, and signals sent or received. A log should be compiled in a simple form so that it could be handed to another navigator without explanations.

(ii) The log should be kept on Form 441, Navigator's Log Book, which is a stiff-backed cover containing a renewable block of printed forms. The upper part of each sheet contains data such as distances, tracks, estimated courses and ground speeds, which are calculated before the flight. On the lower part a record of the navigational work should be entered during flight.

(iii) To prevent confusion, a standard method of making entries in the log should be adopted. The following are the chief points to note :—

(*a*) All figures entered in the log should be followed by a letter or abbreviation which clearly indicates the meaning of the entry as, for example, " T." for " true ", " M." for " magnetic ", " C." for " compass ", " kts." for " knots ", " m.p.h." for " miles per hour ", " P." for " port ", " S." for " starboard ", etc. Other abbreviations, such as " S/C " for " set course ", " A/C " for " altered course ", " E.T.A." for " estimated time of arrival ", " Posn " for " position ", and so on, should be used when the meanings are obvious.

(*b*) All place names must be entered in block letters.

(*c*) If the wind given by meteorological forecasts is used at the beginning of the flight, it should be entered in the appropriate place at the head of the page. When the wind velocity is found in the air, it should be entered in the body of the log and *underlined*, and the method of finding it stated.

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(*d*) When W/T signals are sent or received, the fact should be noted in the log, but it is not necessary to enter the complete message in the navigation log if a W/T log is kept as well.

(*e*) Bearings and courses may be entered as True or Magnetic. It is generally preferable, particularly for the graphical solution of problems, to " work in True ", and true tracks and courses should be entered in columns 2 and 3 of the lower part of the log sheet. Where the fact of setting or altering course is recorded in the body of the log, the magnetic course should be entered. It is unnecessary to complete columns 2 and 3 on every line. This should only be done when course is changed. True bearings, courses, etc., are to be given in W/T signals.

(*f*) The log must always be dated, and signed by the navigator at the foot of each page.

**2. Preparations for a flight**

(i) Maps or charts should be carefully prepared before a flight. Tracks and distances should be measured accurately and entered in the log (*see* chapter II, para. 9). For short flights within Great Britain, the R.A.F. edition, $\frac{1}{4}$-inch map is the standard flying map. For longer flights it will be found convenient to use the 10-mile map, but the corresponding sheets of the $\frac{1}{4}$-inch map should be carried in order to assist the exact fixing of position.

(ii) The general character of the country to be flown over should be studied. In some cases it might be concluded from this preliminary study that it would be undesirable to fly in a direct line and that, in order to avoid flying over a large town, a prohibited area, or high mountains, it would be necessary to make a detour. The height at which a flight should be carried out may be largely determined by the hill features of the country to be flown over. Specially prominent features on or near the track should be noted carefully : it may be found useful to mark these by drawing circles round them in pencil. A time scale marked on the map will also simplify map-reading considerably. The " two-point " method described in para. 9 may be found a simple method of laying down a time scale.

(iii) Maps should be folded in such a way that the track is exposed, the sections are of convenient size to fit the chart board or navigator's table, and each section can be seen in turn by turning over the successive folds.

(iv) Before undertaking a long flight, the fullest advantage must be taken of all available meteorological information. It is not sufficient to obtain only an estimate of the wind at the departure point. Careful study of the weather map will give

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valuable indications of the types of weather and changes of wind velocity to be expected throughout the course of the flight. Weather maps are available at practically all stations at home and in Egypt, Palestine and Iraq. At some stations meteorological information is given by ground signs laid out on the aerodrome.

### 3. The use of navigational instruments

Every pilot or navigator should be thoroughly familiar with the instruments used in air navigation. The following are some of the points that should be noted :—

(i) The magnetic compass is in the main a reliable and accurate instrument, but errors are caused by variations of course and speed. (*See* chapter XIII, para. 4.) It must be remembered that, unless the aircraft is absolutely steady, there may be an error in the reading of a compass amounting to several degrees at any given instant. In taking back bearings on fixed objects or sea markers, where the bearing is not changing, the average of several readings can be assumed to be correct, but a single bearing should always be treated with caution. In order to maintain a steady course, a pilot should steer on a cloud or distant object or by turn indicator, checking the course occasionally from the compass. If a ground object is chosen, it must be a considerable distance ahead. In spite of compass errors, a pilot who uses his compass in this way can be certain of making good the desired course, since the errors will normally balance out over a period of time.

(ii) An air speed indicator does not indicate the true air speed at heights above sea-level, for reasons given in chapter XI, para. 2. The readings of the instrument must be corrected by means of the height and air speed computer. This computed air speed must always be used when navigational problems are to be solved. It should also be remembered that the difference between the indicated air speed and the computed air speed depends chiefly on the height. If, therefore, any considerable change of height is made during a long flight there will be a corresponding change of computed air speed for the same indicated air speed. It may be found convenient for the pilot to alter the indicated air speed so as to keep the computed air speed the same.

(iii) The altimeter does not record the height of the aircraft above the ground over which it is passing. It shows only the approximate height above the zero set on the instrument, for certain assumed atmospheric conditions. The effect of variation of temperature and pressure on altimeter readings is discussed in chapter XI, para. 4, and chapter XVII, para. 4.

To allow for the actual atmospheric conditions, the reading of the altimeter must be corrected by means of the height and

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air speed computer. The dial of the altimeter should be set before the flight is begun, either to zero or to the height of the departure point above sea level. The former is preferable for short flights returning to the same aerodrome, but for longer flights, particularly when landings are to be made en route, the latter is advisable, as the altimeter then registers the height above sea level, and the actual height above the ground can be found by subtracting the height of the ground flown over from the computed altimeter reading.

(iv) Constant practice in the use of such instruments as the course setting bomb sight, tail drift sight, bearing compass, and other navigational instruments is essential in order that accurate results may be obtained without waste of time.

**4. Variation of wind velocity**

In chapter XVII, para. 7, it is explained that the wind velocity varies at different heights. In general, the speed increases with height, and the wind veers, i.e., its angular direction increases. For winds from an easterly point, however, there is sometimes a decrease in speed and a backing, i.e., a decrease in angular direction, though no hard and fast rule can be laid down. The approximate value of the change with height is indicated in meteorological forecasts of wind velocity, or may be obtained from observations during a flight of wind velocities at different heights. (*See* example in para. 7 below.)

Wind velocity may also be expected to change with change of position. Information of such changes may be obtained from meteorological reports based on weather maps.

**5. Practical methods of air navigation**

(i) After taking off and having reached a safe height, the pilot should turn directly on to the required course and maintain the course while climbing to the height at which the flight is to be carried out. Since the air speed will be lower than the normal cruising speed, and since the computed air speed and probably the wind velocity will be constantly changing as the height changes, observations of track and ground speed made while climbing cannot be made use of later in the flight. Consequently, a point on the track a few miles from the aerodrome should be selected, marked on the map, and treated as the departure point for the purpose of checking track and ground speed. The pilot should fly, partly by compass and partly by map reading, in such a way as to pass over the selected point at the required height and air speed and on the given course.

If the time can be spared, it will often be convenient to climb in the vicinity of the aerodrome after taking off and to set course from immediately over the aerodrome at the height at which the flight is to be carried out.

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(ii) Provided that the required track is maintained, the aircraft must arrive at the destination. Since the wind velocity cannot be relied upon to remain exactly the same throughout a flight, the track made good must be checked at frequent intervals and the course adjusted accordingly. The track may be found by any of the methods enumerated in chapter VII, para. 3.

If course is altered by the amount of the error in the track, the aircraft will follow a path approximately parallel to the required track. In order to close the track and bring the aircraft to the destination, course should be altered by rather more than the error in the track. For example, if the track required is 256°, the course steered 264°, and the drift is found to be 12° to port, then the track made good is 252° and the error in the track is 4° to port. If course is altered 4° to starboard, the aircraft will follow a track parallel to the required track, while altering course 5° to starboard will gradually bring it back on to the track.

It should be noted that an alteration of course does not necessarily result in an alteration of track of the same amount. For practical purposes, however, for small alterations, this method is perfectly satisfactory unless the wind is very strong and is blowing from nearly dead ahead or astern. Under these circumstances course should be altered by rather less in a head wind and rather more in a tail wind than calculations would indicate.

(iii) If an aircraft is considerably off the track, the track which must be made good to the destination will differ appreciably from that originally measured, and it is necessary to calculate the course to steer to make good this new track. It is therefore essential that the wind velocity should be known as accurately as possible. Every opportunity should be taken during a flight to measure both the track and the ground speed, and the wind velocity should be calculated at frequent intervals.

When it becomes necessary to calculate the new course, it is advisable to choose a point on the track being made good, which will be reached about 5 to 10 minutes later, and to measure the track from this point to the destination. The necessary calculations can then be made during the run to this point, and course altered on reaching it. (*See* example in para. 6 below.) Alternatively, course may be altered at once, the approximate course being arrived at by estimation, and the accurate course calculated subsequently.

(iv) In flights over the land the most obvious way of determining the track and ground speed is to fix the position of the aircraft from time to time by map reading. The angle of drift, from which the track may be found at once (*see* chapter VII, para. 3 (iii) ), may be determined by means of the tail

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drift sight or course setting bomb sight. When flying in or above clouds, bearings obtained by direction finding W/T are often of great value for fixing position. (*See* chapter VI.)

In flights over the sea the methods of navigation must necessarily differ somewhat from those used over the land. Position can normally only be fixed by obtaining visual or D.F. W/T position lines. Navigation is carried out mainly by a combination of dead reckoning (i.e., estimating the wind velocity and calculating the track and ground speed) and frequent determination of the track. When the speed of the surface wind is not less than 15 to 20 knots, the drift relative to the surface of the sea may be found approximately by means of the course setting bomb sight, but this is not generally practicable if the surface is calm. The most reliable method of determining the track is to take back bearings, by means of a bearing compass or bearing plate, of the departure point and of sea markers or smoke floats dropped from the aircraft. The effectiveness of sea markers and smoke floats depends on the state of the sea. For example, the ordinary sea marker, composed of aluminium powder which scatters on striking the water, may only last for two or three minutes in a breaking sea, while in calm weather it will remain visible considerably longer.

(v) Observations made for the purpose of checking track and ground speed must be as accurate as possible. If the bearing and distance between two fixes are to be used for calculating track and ground speed, these fixes should not be less than 12–15 miles apart. Times recorded in the log should be taken to the nearest half-minute, and distances should be measured to the nearest half-mile. The importance of measuring times and distances to this degree of accuracy is shown by the following examples :—

12 miles in 8 mins. = 90 m.p.h.
12 miles in 7½ mins. = 96 m.p.h.
12½ miles in 7½ mins. = 100 m.p.h.

(vi) Close co-operation between the pilot and the navigator is essential for successful navigation. The pilot will normally decide at what height and air speed he intends to fly, and should inform the navigator if changes of height or speed become necessary. Instructions given by the navigator to the pilot relating to alterations of course, etc., should be simple, should include all necessary information, and should always be written clearly on a message slip.

(vii) Position signals should be transmitted by W/T throughout the flight at pre-arranged intervals. Such signals should include the following details :—aircraft number, position, track and ground speed, next position and estimated time of arrival, and time of origin.

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**6. Log of a flight from Netheravon to Sealand.** (Fig. 39)

(i) An aircraft is ordered to proceed from Netheravon to Sealand. The necessary maps are first obtained and studied: these are sheets 5, 8 and 11 of the ¼-inch map and sheet 3 of the 10-mile map. The track is laid off on the 10-mile map and transferred to the ¼-inch sheets. The track may be measured from the grid lines, the deviation of the grid mid-way between Netheravon and Sealand being found by reference to the ¼-inch map and applied to the angle measured. The track measured with reference to the grid lines is 340°, the grid deviation is 1° W., and the required track is therefore 339° T.

(ii) The meteorological forecast gives the wind velocity at the departure point and indicates the probability that it will back during the flight. The forecast also indicates that the general level of the cloud base will be 2,000–3,000 feet, but that low cloud may be encountered about half-way along the route. Study of the maps shows that the track passes near several areas of high ground, including the Malvern Hills (1,400 feet), the Clee Hills (1,750 and 1,790 feet) and the Wrekin (1,330 feet), and it is therefore decided that it may be necessary to fly in or above the clouds for some part of the route. A weather report obtained from Sealand immediately before the flight is commenced gives the height of the cloud base as 1,000–2,000 feet and visibility 3–6 miles.

(iii) The pilot takes off and sets course at once, climbing steadily to 2,000 feet, at which height it has been decided to fly. It is seen from the map that the track crosses a railway line a few miles from Netheravon, and this is selected as being a suitable point from which to take departure. The pilot therefore adjusts his course after leaving Netheravon so that he will cross the railway at the required point, at the desired height and air speed and on the course given to him by the navigator. Position is fixed about 12 miles from the departure point, the track and ground speed found and the wind velocity calculated. Course is altered to bring the track parallel to the required track. A few minutes later, position is again fixed by map reading and the track and ground speed checked. The estimated time of arrival at Sealand is also calculated. Low clouds are seen ahead, and the pilot climbs to 4,000 feet. Owing to the fact that the wind velocity is probably different at the greater height, the track and ground speed are checked again as soon as possible by two fixes, one obtained by map reading and the other by D.F. W/T while the aircraft is above the clouds. The new track and ground speed made good are found and the new wind velocity calculated. Since the error in the track is fairly large, a line is drawn on the map between the two fixes and extended to the D.R. position for a time a few minutes later. The track and distance from this point to

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FORM 441. **NAVIGATOR'S LOG SHEET.**

Date 26-2-35. Aeroplane Heyford K9999. Pilot F/Lt Smith.
Orders for Flight Proceed from NETHERAVON to SEALAND. Squadron 372 (B)
Wind at 2000 Ft. 30 m.p.h. from 020 deg: (True.)

| 1 From | To | 2 Air Speed. | 3 Track True. | 4 Distance. | 5 Course True. | 6 Varn. | 7 Course Mag. | 8 Ground Speed. | 9 Time. | 10 E.T.A. |
|---|---|---|---|---|---|---|---|---|---|---|
| NETHERAVON. | SEALAND. | 130 | 339 | 146 | 348 | 13W | 001 | 106 | 83 | 1123 |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |

## LOG TO BE KEPT IN THE AIR.

| TIME. | TRACK REQD. | COURSE STEERED. | OBSERVATION. |
|---|---|---|---|
| 1000 | 339 | 348 | Airborne. S/C 001° M for SEALAND. A/S. 100 m.p.h. |
| 1005½ | | | Poen. (V) U5780 Height 2000' A/S. 130 m.p.h. |
| 1007 | | | Poen. sig. sent. |
| 1012 | | | CLYFFE PYPARD Track 342°T. G/S. 106 m.p.h. |
| 1013 | | 345 | A/C 358°M W.V. 010°T 27 m.p.h. (2 fixs) |
| 1020 | | | KEMBLE STN. Track 339°T G/S 105 m.p.h. |
| | | | E.T.A. SEALAND. 1125 hrs. |
| 1022 | | | Low clouds ahead. Climbing. A/S 100 m.p.h. |
| 1027 | | | Height 4000'. A/S 130 m.p.h. |
| 1028½ | | | BIRDLIP seen through clouds. Track 339°T |
| 1032 | | | Poen. sig. sent. |
| 1044 | | | Requested poen. by D.F. W/T. |
| 1047½ | | | Poen. by D.F. W/T (V) P2784. Track 347°T. G/S 98 m.p.h. |
| | | | W.V. 339°T 33 m.p.h. (2 fixs) |
| 1054 | 333 | 335 | A/C 348°M. E.T.A. SEALAND 1133 hrs. |
| 1100 | | | Poen. sig. sent. |
| 1102 | | | Descending through clouds. |
| 1104 | | | IRON BRIDGE. |
| 1109 | | | Drift by T.D.S. 4°P. Height 1500'. Vis. 3 miles. |
| 1111 | | 338 | A/C 351° M. |
| 1114½ | | | WEM. Track 333°T, G/S 109 m.p.h. E.T.A. SEALAND 1130 hrs. |
| 1120 | | | Drift by T.D.S. 4°P. |
| 1123 | | | Poen. sig. sent. |
| 1131 | | | Landed SEALAND. |

(21172) Wt. 10698/248 1200 pads 6/34 Hw. T.5203

A.M. Jones. F/O. Navigator.

FIG. 39.—Air navigation log.

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FORM 442.

# NAVIGATOR'S LOG SHEET.

Date 14·3·35 Aeroplane Perth K 1111. Pilot F/Lt Brown.

Orders for Flight Proceed from PEMBROKE DOCK to SCILLIES. Squadron 413. (F.B)

Wind at 1000 Ft. 25 kts est. from 240 deg. (True.)

| 1 From | 2 To | 3 Air Speed. | 4 Track True. | 5 Distance. | 6 Course True. | 7 Varn. | 8 Course Mag. | 9 Ground Speed. | 10 Time. | E.T.A. |
|---|---|---|---|---|---|---|---|---|---|---|
| PEMBROKE DOCK | SCILLIES. | 90 | 206 | 118 | 215 | 14W | 229 | 68 | 104 | 1552 |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |

## LOG TO BE KEPT IN THE AIR.

| TIME. | TRACK REQD | COURSE STEERED. | OBSERVATION. |
|---|---|---|---|
| 1406 | — | — | Airborne. |
| 1408 | 206 | 215 | over PEMBROKE DOCK. Height 1000'. Vis. 10-12 miles. |
| | | | S/C 229° M for SCILLIES. |
| 1410 | | | Departure sig. sent. |
| 1412 | | | B.B. PEMBROKE DOCK. 044°M = 030°T Track 210°T. |
| 1413 | | 211 | A/C 225°M |
| 1416½ | | | ST. GOVEN L.V. bears 133°M = 119°T. |
| | | | G/s 71 kts. E.T.A. SCILLIES 1548 hrs. |
| 1431 | | | B.B. sea marker 034°M = 020°T. Track 200°T. |
| 1433 | | 218 | A/C 232°M. |
| 1434 | | | W.V. 260°T 20 kts (Estimated) |
| | | | G/s therefore = 78 kts E.T.A. SCILLIES. 1540 hrs. |
| 1439 | | | Poan. sig. sent. |
| 1443 | | | Bearing from MOUNTBATTEN 310°T. G/s 75 kts. |
| 1446 | | | B.B. sea marker 041°M = 027°T. Track 207°T. |
| | | | W.V. 264°T 22 kts. (Track and G/s) |
| 1505 | | | Bearing from MOUNTBATTEN 286°T. |
| | | | Fix 50° 40' N. 05° 50' W. |
| 1510 | | | Poan. sig. sent. |
| 1512 | | | W.V. 256° 20 kts. (Estimated) |
| | | | G/S therefore = 76 kts. Track 208°T. |
| 1516 | | 216 | A/C 230°M. |
| 1531 | | | SEVEN STONES L.V. bears 246°M = 232°T, |
| | | | about 5 m. G/S 81 kts. E.T.A. SCILLIES 1540 hrs |
| 1538 | | | Poan. sig. sent. |
| 1540 | | | SCILLIES. |
| 1542 | | | Alighted. |

(21172) Wt. 10899/248 1200 pads 6/34 Hw. T.5303

P. Q. Robinson. Flg. Officer Navigator.

FIG. 40.—Air navigation log.

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Sealand are measured and the new course calculated. After descending through the clouds position is fixed by map reading and the required track is maintained by observations of drift by means of the tail drift sight. The ground speed and E.T.A. Sealand are found by obtaining another fix. A final position signal is sent a few minutes before Sealand is reached.

**7. Log of a flight from Pembroke Dock to Scillies.** (Fig. 40)

(i) A flying boat is ordered to proceed from Pembroke Dock to Scillies. The charts required are chart No. 2675A and large-scale charts of the area round Pembroke Dock and of the Scilly Islands. The track is laid off and measured and the distance is measured by reference to the latitude scale. (*See* chapter III, para. 5.)

(ii) The meteorological forecast indicates fine weather with winds between S.W. and W. at 20–25 knots. The wind velocity at Pembroke Dock is given as 25 knots from 240° T. at 1,000 feet, and this wind is used to calculate the course to steer and the ground speed. The wind velocity at the surface is approximately 20 knots from 235° T.

(iii) The pilot takes off and sets course over Pembroke Dock at 1,000 feet. Soon after setting course, a back bearing of the departure point is taken by means of a bearing compass and indicates that the track made good is 210° instead of the desired track of 206°. Course is therefore altered at once 4 degrees to port. The ground speed is checked by a bearing of the St. Goven light vessel. About 15 minutes later the track is checked by a back bearing of a sea marker and is found to be 200° T. Course is therefore altered 7° to starboard in order to correct the error in track of 6° and bring the aircraft back on to the track. A change of 6 degrees in the drift suggests a considerable change in the wind velocity. This is estimated as about 15 knots from 255° T. at the surface. At the departure point the wind speed at 1,000 feet was 5 knots greater than at the surface, with a veer of 5°. These figures are applied to the estimated surface wind to give the estimated wind at 1,000 feet. A W/T position line approximately at right angles to the track gives a check on the ground speed, and a back bearing of another sea marker affords a means of checking the track. The wind velocity can therefore be calculated. A second W/T bearing is obtained, and the first W/T position line is transferred to give a fix. This gives the position of the aircraft as about 3 miles west of the D.R. position. The fix cannot be regarded as reliable, because the position lines cut at only 24°, but it indicates that the aircraft is probably to the west of the track. This is supported by estimating the wind velocity and using it to calculate the track and ground speed being made good. Course is accordingly altered 2 degrees to

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port. Later, the Seven Stones light vessel is seen, and a bearing taken of it shows that the D.R. position is approximately correct. The course is therefore maintained until the Scillies are sighted.

**8. The pilot-navigator**

(i) The pilot of a single-seater aircraft, or any pilot who is not assisted by an observer skilled in navigation, cannot use such instruments as the chart board, bearing compass, tail drift sight, etc. It must not be assumed, however, that the pilot-navigator is not concerned with the various methods of air navigation laid down in this manual: if he has a good knowledge of these methods he can, with continuous practice, make estimations and mental calculations with reasonable accuracy.

(ii) A successful cross-country or oversea flight, particularly one undertaken under adverse weather conditions, depends very largely upon careful preparation. Maps should be prepared and meteorological conditions studied as described in para. 2 above. Tracks, distances, estimated courses and times of arrival and times of passing prominent places on the track should be worked out, and recorded in a log. A pilot-navigator's log book (Form 433) may be used, or the details may be entered on a Route Card (Form 1485).

**9. Methods of navigation for the pilot-navigator**

(i) The actual methods used by the pilot-navigator must depend on the particular circumstances of the flight. With a visibility of 20–30 miles, a favourable weather forecast, and territory abounding in easily distinguishable features, such as mountains, large towns, coast lines, lakes, etc., successful navigation depends on little more than an ability to read a map in general terms. With low visibility and/or comparatively featureless country, steering an accurate course by the compass becomes of primary importance. The track and ground speed must be checked frequently. Rapid and accurate map reading is essential, in order that the exact position of the aircraft may be determined at frequent intervals.

(ii) The course set from the departure point should be that calculated before flight. If for any reason it is not possible to calculate the course before flight, course may be set to make good the desired track by the following means, known as the "*two point*" method. Two conspicuous objects on the track about 5–10 miles apart, over which the aircraft should pass soon after leaving the aerodrome, are selected and marked on the map. If height is gained over the aerodrome before setting course, the aerodrome may be used as the first of these points. The aircraft is then flown on an appropriate course to make it pass over the selected points and this course is maintained.

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This method is particularly useful if it is necessary to alter course during a flight to a destination other than that originally intended. Constant practice will enable the pilot to estimate approximately the course to steer by a consideration of the triangle of velocities. For any given air speed and wind speed the maximum drift is experienced when the direction of the wind is at right angles to the track. As long as the wind speed is not more than half the air speed the maximum drift (in degrees) can be taken as equal to $\frac{\text{wind speed } (W)}{\text{air speed } (A)} \times 60$. When the angle between wind direction and track is 30° (or 150°) drift $= \frac{W}{A} \times 30$ and when the angle between wind direction and track is 60° (or 120°) drift $= \frac{W}{A} \times 50$ (approx.).

(iii) If the aircraft is found to be off the track, the amount of alteration of course necessary to bring it back can be estimated without difficulty if it is remembered that at a distance of 60 miles an error in the track of one degree will result in an error of position of about one mile. Thus, if the aircraft is 2 miles from the track after travelling 30 miles from the departure point, the error in the track is about 4°. If course is altered by 4°, the aircraft will proceed parallel to the required track, but 2 miles from it. Suppose that the aircraft is 60 miles from the destination. In order to close the track, a further alteration of 2° must be made, so that a total alteration of course of 6° will bring the aircraft to the destination. A table showing the error in the track for different distances from the

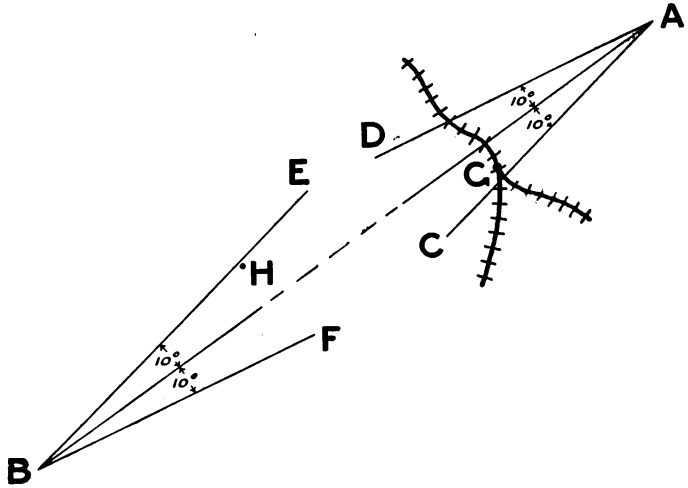


FIG. 42.—Method of air navigation with the aid of 10-degree lines.

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required track and from the point of departure is given in appendix XI. It should be noted that the angular error obtained is the error in the *track* and not the error in the *course* steered. (*See* para. 5 (ii) above.)

(iv) An alternative method of maintaining the track is the " 10° *line* " method (Fig. 42). A pilot wishes to fly from A to B. He draws his track on the map in the usual way but marks the lines AC, AD, BE, BF, each making an angle of 10° with the track. He then selects a suitable " line " landmark, such as a railway or river, which crosses his track, some portion of which he must cross and recognise, even in bad visibility, provided that his actual track is within 10° to 12° of the intended one. This landmark should be about 10–20 miles from A. Suppose that the pilot finds that he crosses the landmark at a point G (Fig. 42). By eye he can estimate that his track is about 7° to the left of AB, and by altering course 7° to starboard, he will follow a track approximately parallel to AB. By altering course 8° to starboard he will gradually close his track again.

The 10° lines at the destination B help to indicate the alteration of course necessary if the pilot is off the track. Suppose that he finds himself over H, then he must alter course 9° to port in order to fly directly over B.

(v) Over featureless country or over the sea, where the pilot-navigator cannot check his track by frequent fixing of position, he must rely on observations of drift and estimations of change of wind velocity. Drift markings on the main planes (*see* chapter XI, para. 15) are of great assistance to the pilot-navigator in estimating drift. There can be no doubt about reaching the desired destination so long as it is possible to check and, when necessary, modify the course steered by observations of drift. Thus the angle of drift is a most important factor to the pilot-navigator, and no opportunity to observe it should ever be neglected.

In the absence of any means of observing drift, estimation of change of wind velocity may often prove useful, particularly in flying over the sea or above clouds. (*See* chapter VIII, para. 1, and para. 4 of this chapter.) For example, suppose that an aircraft is flying on a southerly course and that it becomes evident that the wind, which is blowing from a westerly point, has freshened considerably: there must be a corresponding increase of port drift, and course should therefore be altered to starboard.

(vi) It is of the greatest importance, particularly on a long flight, that the pilot-navigator should keep a check on the ground speed, and so know at what times he may expect to pass prominent landmarks on or near the track. By this means fixing position is considerably simplified. The simplest



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method of checking ground speed is to compare the actual times of passing prominent points on the track with the times calculated before flight. For example, if the expected time of passing a certain place is ten minutes after leaving the departure point and that place is actually reached in nine minutes, the expected times of passing other points on the track will be reduced by one minute in ten.

The " two point " method (*see* para. 9 (ii) above) also provides a convenient means of checking the ground speed. The track is divided into sections each of which is equal to the length between the selected points, and the points thus marked on the map are numbered 1, 2, 3, etc. The pilot times his run between the first two points and so can estimate his time of arrival at each successive point. For example, consider a flight from Andover to Gosport. (*See* Plate II.) A few miles from Andover, the track crosses a railway at Leckford. The track is therefore divided into sections equal to the distance between Andover aerodrome and Leckford and numbered as shown. The pilot takes off, gains height over the aerodrome, and sets course for Gosport. Three and a half minutes after leaving Andover he sees the railway line at Leckford immediately below him. He then knows that 3½ minutes later he should pass over the centre of a large wood, and after a further 3½ minutes (i.e. 10½ minutes after leaving Andover) he should cross another railway near Otterbourne, and so on, and should finally reach Gosport about 20 minutes after leaving Andover.

(vii) While the ground is visible the map and ground should be compared frequently: when in or above the clouds, the pilot should note on the map the area over which he should be passing, so that when he comes down through the clouds he is prepared for the landmarks he may expect to see. When visibility deteriorates, the pilot may find that his attention is required almost entirely for flying his aircraft. He should then concentrate on keeping the course which his previous observations showed to be making good the desired track. When doubt as to his actual position arises, the pilot should generally have some idea from his map and record of D.R. times as to the district he is over. He should then try to locate on the ground some distinctive landmark shown on the map. Failing this, and still continuing his course, he should select some conspicuous landmark, or combination of landmarks, on the ground, and then, keeping it in view, try to locate it on the map. If, for example, a railway is selected, its direction should be carefully noted and an attempt made to distinguish features, such as junctions, bridges, etc. If this is unsuccessful, the pilot should determine from the map whether there is another railway having approximately the same bearing, within a reasonable distance of the first. By a process of elimination,

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a position should eventually be identified with certainty, and although this appears a lengthy operation it is, in fact, generally simple and effective provided that the pilot can read his map quickly and intelligently.

**10. Air navigation by night**

(i) The general principles of air navigation are applicable to night as well as to day flying, but owing to the increased difficulties experienced in locating landmarks and to the fact that artificial light is required for examination of the map and for the use of navigational instruments, air navigation in the darkness requires special training and experience. Before making a long flight by night it is essential that the pilot and the navigator should be thoroughly proficient in map reading and in the mechanical methods of air navigation by day.

(ii) The fixing of position at night depends to a large extent on observation of lights, and a careful study of the lights shown in various localities at different times should therefore be made. Each town, large railway station, port or dockyard possesses a characteristic arrangement of lights, and may thus be recognised by night, but it should be remembered that the lights may be extinguished during the night, thus altering the shape and general appearance of the town or other landmark during the later hours. Map reading at night is discussed in chapter IV, para. 5.

(iii) Lights designed to assist air and marine navigation are of the greatest importance. Maps and charts of the area in which the proposed track lies should be carefully examined before the flight and the position and distinctive characteristics of the various lights near the track should be noted.

Lights intended as aids to air navigation are classed as aerodrome beacons, airway beacons, or air navigation beacons, according to whether they are situated at aerodromes, on or near recognised airways or elsewhere where they may be of general assistance to air navigation.

Marine lights include lighthouses, lightships and light buoys. Due allowance should be made for the fact that marine lights may be masked on the landward side, and that when visible, they may be seen from the air at a much greater distance than that specified on the chart. (*See* chapter III, para. 7.)

(v) A pilot flying at night will often find it of assistance in maintaining a steady course to select a bright star or distant light and keep it in line with a point on the aircraft. It should, however, be borne in mind that stars appear to revolve anticlockwise round the Pole Star through an angle of about 15° in one hour. (For location of the Pole Star and recognition of



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the principal stars *see* A.P. 1456, Manual of Air Navigation, Vol. II, chapter XVIII.) It is generally easier to steer a steady course at night, as the air is usually less " bumpy ".

(vi) Every opportunity should be taken at night to check drift. A single light on the ground is sufficient to give an observation for drift. Drift wires on the course setting bomb sight, being luminous, can be seen on the darkest night, while the light of an electric torch is sufficient for reading the figures on the bearing compass or bearing plate. Alterations in the strength or direction of the wind during the flight should be carefully noted and allowed for.

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## CHAPTER X.—OPERATIONS AND TACTICAL EXERCISES

### 1. Relative velocity

(i) Various problems arise in air navigation which can be solved easily by the application of the theory of *relative velocity*. This theory is very simple, but unless it is thoroughly understood, it is likely that difficulties will arise. Suppose that two trains are moving on parallel lines of a railway, and have the same speeds in the same direction. A passenger in either train would observe no velocity whatever in the other, which would appear to him to be at rest. The velocity of either train relative to the other in this case is zero. If one train, A, has a velocity of 40 m.p.h. towards north and the other, B, has a velocity of 30 m.p.h. in the same direction, an observer in B will see A passing him at 10 m.p.h. and would describe the velocity of A relative to B as 10 m.p.h. towards north. An observer in A would see B falling behind at 10 m.p.h. and would describe the velocity of B relative to A as 10 m.p.h. south. Expressed generally, *the velocity of one body, A, relative to another body, B, is equal and opposite to the velocity of B relative to A.*

(ii) In Fig. 43 imagine an aircraft at the point C, 120 miles west of the point A and travelling towards it at 120 m.p.h. A second aircraft at B, 90 miles south of A, is travelling

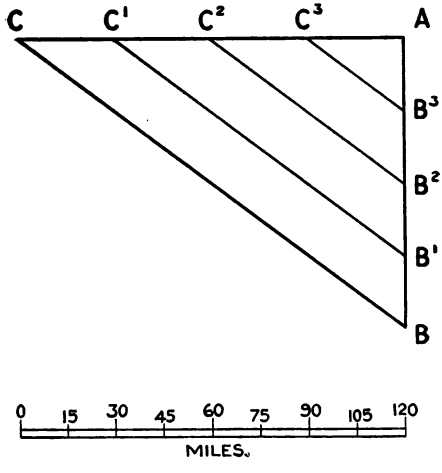


FIG. 43.—Relative velocity.

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towards the same point at 90 m.p.h. Clearly, at the end of one hour, both aircraft will meet at the point A, while at equal spaces of time, say 15 minutes, B and C will respectively occupy in succession the points $B^1$, $B^2$, $B^3$, and $C^1$, $C^2$, $C^3$. It will be seen that the lines BC, $B^1C^1$ etc. are parallel to each other, and that at any instant before the aircraft meet, C will appear to move in the direction CB to an observer in B, while B appears to move in a direction BC to an observer in C. The line BC is properly called the line of relative velocity, but it may be more convenient to refer to it as the *line of approach.* The relative speed along the line of approach is called the *speed of approach.*

(iii) Supposing the two aircraft B and C were both equally influenced by a wind of say, 30 m.p.h. from S.W. They would still meet at the end of one hour, although the point of meeting would be 30 miles N.E. of the point A. Expressed generally, *the relative velocity between two moving bodies remains unaltered if an additional equal velocity in the same sense be applied to both.* Advantage is taken of this in solving various problems. Reverting to Fig. 43, C has a velocity of 120 m.p.h. east and B a velocity of 90 m.p.h. north. Suppose a velocity of 120 m.p.h. west be applied to both, then C becomes stationary, while B now has two component velocities represented in Fig. 44 by BA and BD. By drawing the diagonal of the parallelogram of velocities BC, it is seen that the resultant of these is the velocity BC, so that it still appears that C being at rest, B will meet it in exactly one hour. It should be carefully noticed, however, that neither aircraft actually moves along the line of approach.

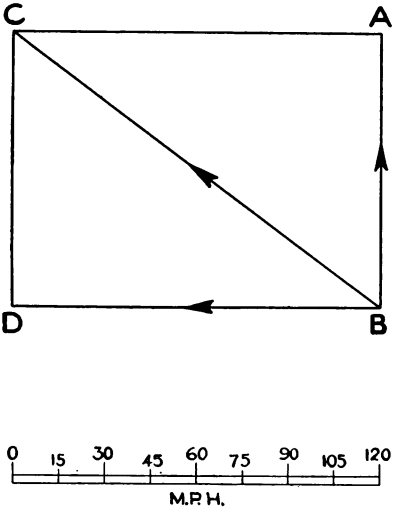


FIG. 44.—Relative velocity.

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**2. Solution of problems**

Problems which arise when aircraft carry out operations and tactical exercises involve normally the solution of a number of triangles. They can be worked out on a course and distance calculator, but this necessitates the triangles being solved successively, and in consequence any instrumental error tends to accumulate. Problems involving the solution of two triangles can be worked on the course and wind calculator, type " D ", in one setting (*see* chapter XI, para. 9). For work in the air, the more complicated tactical problems are better plotted on the map or chart, on paper, or on the chart board, as may be most convenient. Care, accuracy, and neatness are essential for exact results in the graphical solution of problems. It is desirable, in order to reduce error, to use the largest scale possible. Distances and velocities need not be represented to the same scale, but all distances must be to the same scale, and similarly with all velocities.

When problems are plotted on a map or chart, confusion may arise between air positions, D.R. positions and fixes. These positions should therefore be identified by drawing a small circle round each one and writing " Air ", " D.R. ", or " Fix " nearby, together with the corresponding time.

**3. Interception of aircraft or surface craft**

(i) When an aircraft is told to join a formation or another aircraft, the pilot will usually be told the course and air speed of the formation or aircraft. On the other hand, when an enemy aircraft is to be intercepted, the probability is that the track and ground speed only will be known. This also applies when ordered to join a ship, as her course and speed may be taken as representing the track and ground speed. Thus the problem falls into two distinct cases, according to whether the course or track of the craft to be intercepted is known. The former case will be considered first. Provided the craft are not separated by a very great distance, the effect of wind will be the same on both craft. This must be assumed in any event. Thus, as far as the relative velocity of one craft to the other is concerned, the wind may be neglected.

(ii) *Example.*—To find the true course of an aircraft A to intercept an aircraft B, bearing 045° T. distant 60 miles from A. B is steering 270° T. at 130 m.p.h. A's air speed is 160 m.p.h. Wind from 040° T. at 30 m.p.h.

From A, lay off AB, 045° T. 60 miles to a suitable scale. (*See* Fig. 45). Then A and B are the relative positions of the two craft. *Reduce the aircraft B to rest* by giving a velocity equal and opposite to its speed and course to both A and B.

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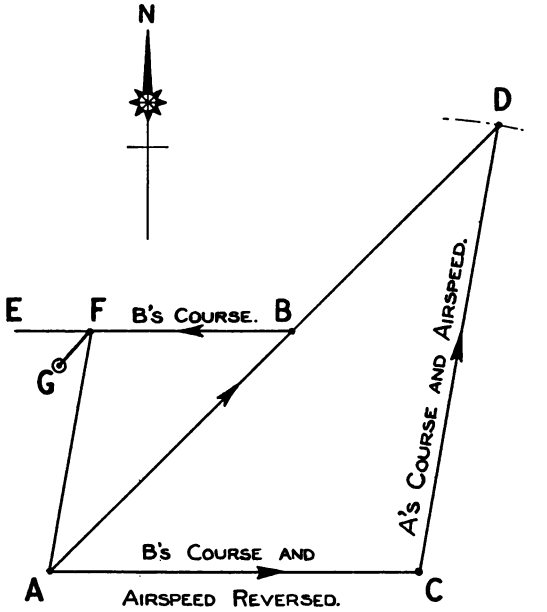
Then one velocity of A is 090° T., 130 m.p.h.

From A lay off AC 090° T., 130 m.p.h. to a suitable scale.

The problem may now be re-stated very simply thus :—To construct a triangle of velocities of which AC is one component, AB (produced if necessary) the resultant, and the course and air speed of the craft A the second component.



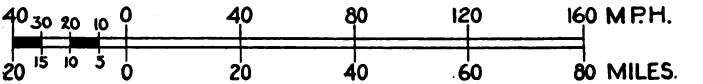




Fig. 45.—Interception when course of other craft is known.

With C as centre, and radius 160 m.p.h. to scale, draw an arc cutting AB produced at the point D. Join CD. Then CD gives A's course to steer.

From the diagram the course to steer is 010° T.

The *time of interception* is an important consideration. The line of approach is AD, and the speed of approach is represented by the length AD. From the diagram the speed of approach is 223 m.p.h. As the distance to be made good is 60 miles, the time of interception is $\frac{60}{223}$ hours, or 16 minutes.

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The *geographical position of interception* is found by considering the courses of the two craft and the wind. Suppose there were no wind, then B would travel in the direction BE (270° T.) at 130 m.p.h. A's direction will be along a line from A, parallel to CD (AF), and F would be the place of interception after 16 minutes.

Actually both aircraft have been influenced by a wind of 30 m.p.h. for 16 minutes: thus both will be carried down wind $\frac{16}{60} \times 30$ miles or 8 miles.

From F draw FG 220°, 8 miles. Then G represents the geographical position of interception.

(It should be noticed that the triangle ACD is a triangle of velocities whereas the sides of the triangle AFB represent distances. FG is also a distance.)

(iii) *Solution by C.D.C.*—In this problem there is only one triangle to be solved to find the course to steer and time of interception. The problem is solved in exactly the same way as the problem of finding the course to steer to make good a given track, knowing the wind, but in this case the course and air speed of B are set on the C.D.C. instead of the wind velocity.

Set the arrow of the centre disc to the bearing of B, i.e., 045° T.

Set arm and pointer A to B's course (270° T.) and half B's air speed (65 m.p.h.) (Half the air speed is set because the scale does not read up to the actual speed.)

Set pointer B to half A's air speed (80 m.p.h.) and move arm B till the pointer is on the same line parallel to the centre arrow as pointer A.

Then the direction of pointer B gives A's course to steer, and the distance between the pointers gives half the speed of approach.

To find the time of interception, put the arrow on the inner scale on the back of the C.D.C. against the speed of approach on the outer scale, and read off the time on the inner scale against the distance of B from A (i.e., 60 miles) on the outer scale.

To find the geographical position of interception it is necessary to plot as above.

It will be noticed that the centre of the C.D.C. represents the point C in Fig. 45.

(iv) *Example.*—To find the course for an aeroplane A to steer in order to intercept an enemy aircraft B reported to be distant 60 miles, bearing 045° T., making good a track of

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270° T. at 100 m.p.h. A's air speed is 150 m.p.h. Wind 315° T. at 30 m.p.h. Find also the time taken to intercept, and place of interception.

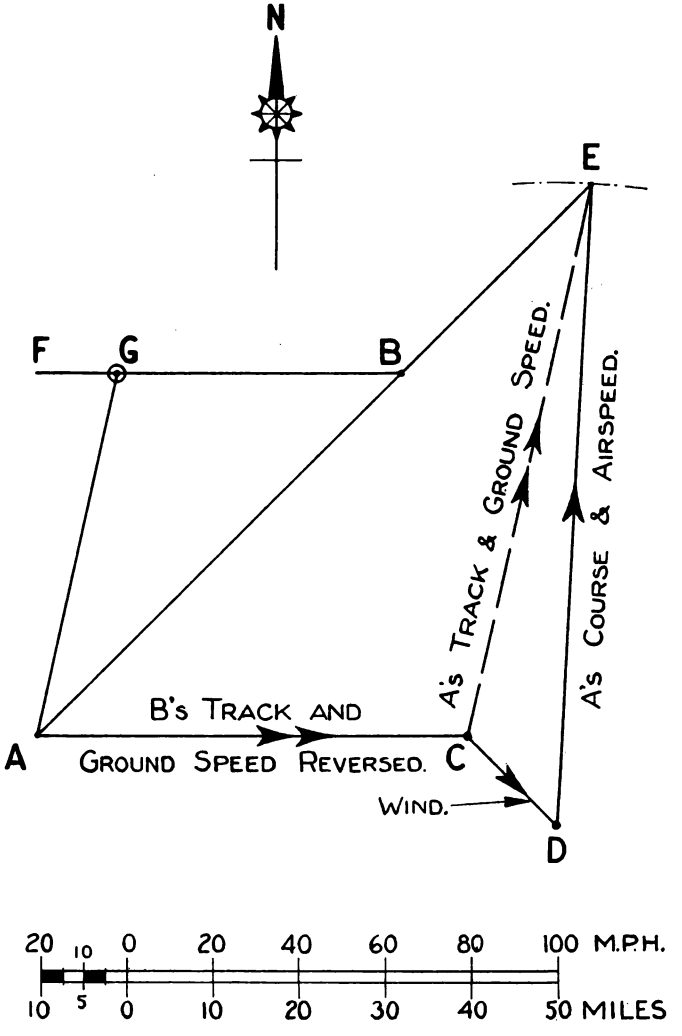


FIG. 46.—Interception when track of other craft is known.

From A lay off AB, 045° T. 60 miles to a suitable scale. (Fig. 46.) Then A and B give the relative positions of the two aircraft.

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*Reduce the craft to be intercepted to rest* by giving a velocity equal and opposite to its track and ground speed to both A and B.

AC represents the enemy craft's track and ground speed reversed.

From C lay off CD, 135° 30 m.p.h. to represent the wind (*down wind*).

With D as centre, and radius 150 m.p.h. to scale, draw an arc cutting AB produced at the point E. Join DE. Then DE gives A's course to steer ; from the diagram this will be found to be 003° T.

(If the points C and E are joined, CE gives A's track and ground speed.)

The *time of interception* is found from the line of approach AB as in the previous problem. The speed of approach is represented by AE, and is 182 m.p.h. Then the time of interception equals $\frac{AB}{AE} = \frac{60}{182}$ hours, or 20 minutes.

As the tracks of both aircraft are known, the *position of interception* is found by drawing BF in the direction of B's track and from A, a line AG parallel to CE (A's track) cutting BF in G. Then G represents the place of interception.

If it is required to join a ship or fleet, the problem is solved by the method shown in this example, using the ship's course and speed as track and ground speed.

(v) *Solution by C.D.C.*—This problem can be solved by C.D.C. in two stages. It is first necessary to find B's course and air speed, track and wind velocity being given. When this is obtained, the interception is worked out as in sub-para. (iii).

**4. Keeping station**

Many variations of this problem are possible, but all are solved on the same principles.

*Example.*—An aircraft carrier is steaming 070° T. at 20 knots and an aircraft is patrolling in station about a point 20 miles distant on a bearing 45° green. The aircraft is ordered to open out to 60 miles, preserving the bearing, and then to return to the carrier. Air speed 90 knots, wind 360° T. at 20 knots. Find the courses to steer and the time taken in going out and returning.

Let A be the aircraft and B the carrier. (Fig. 47.)

From B lay off the course of the carrier and lay down A, the first station of the aircraft, 20 miles 45° green relative to the course of the carrier.

Produce BA both ways to some points C and D, and mark off A′, the second station of the aircraft.

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*Reduce the carrier to rest* by giving a velocity equal and opposite to its course and speed to both A and B.

AE represents the course and speed of the carrier reversed. (*Note.*—In this example it has been found convenient to use equal scales for distances and velocities.)

From E lay off EF to represent the wind (*down wind*). With centre F and radius 90 knots (A's air speed) to scale draw arcs cutting DC in the points G and H. Join FG, FH.

Then FG is the course out (094° T.) and FH the course back (316° T.) AG represents the speed of opening and AH the speed of closing.

Speed of opening = 78·5 knots and speed of closing = 89·5 knots.

The time out $= \frac{AA'}{AG}$ hr. $= \frac{40}{78{\cdot}5}$ hr. $= 30\frac{1}{2}$ minutes.

The time home (since the aircraft is to return to the carrier) $= \frac{A'B}{AH}$ hrs. $= \frac{60}{89{\cdot}5}$ hrs. $= 40$ minutes.

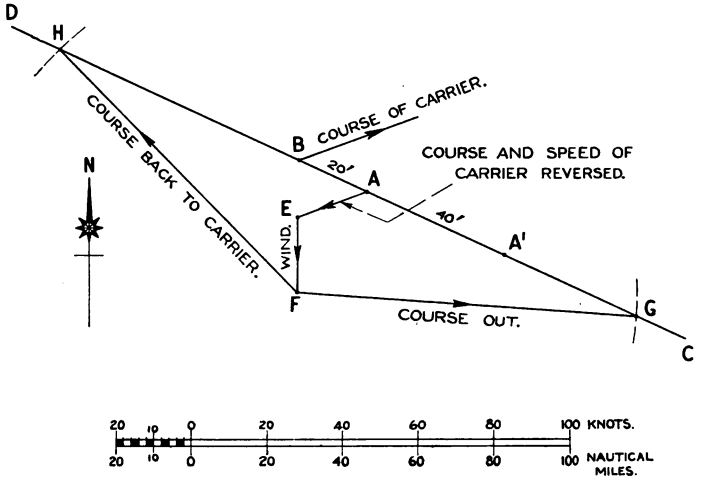


FIG. 47.—Keeping station.

## 5. Changing station

*Example.*—A seaplane is patrolling about a position 20 miles on a bearing of 135° green from the battle fleet which is steaming 023° T. at 20 knots. The aircraft is ordered to take station 40 miles on a bearing 090° green. Air speed 90 knots, wind 270° T. at 15 knots. To find the course to steer and the time required to get into the new station.

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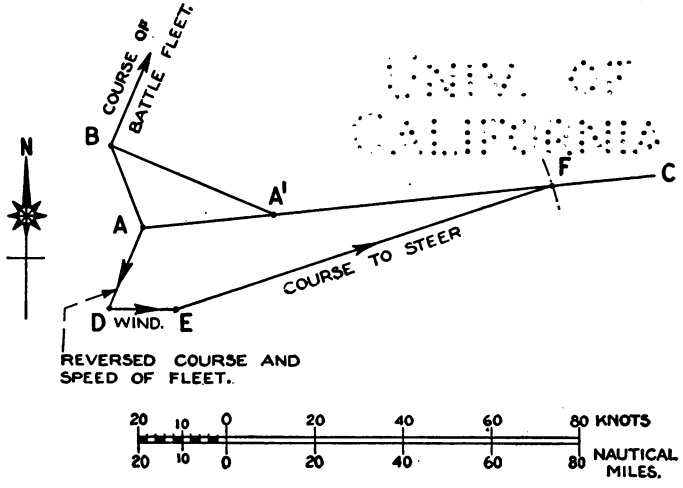


FIG. 48.—Changing station.

Let A be the seaplane and B the battle fleet. (Fig. 48.)

From B lay off a line 023° T. to represent the course of the battle fleet. Then A, the first station of the aircraft, is 20 nautical miles 135° relative to the course of the fleet from B. A′ (the second station of the aircraft) is 40 nautical miles 090° relative to the course of the fleet from B.

Join AA′ and produce to some point C.

The distance AA′ is to be made good relative to the fleet: by measurement the distance is 29 nautical miles.

*Reduce the fleet to rest* and lay off from A the line AD 203° T. 20 knots to scale to represent the reversed course and speed of the fleet.

From D lay off DE, 090° T. 15 knots, to represent the wind (*down wind*).

From E with radius 90 knots (air speed) draw an arc cutting AC in the point F. Join EF.

Then EF represents the course to steer (072° T.).

AF represents the speed of approach, 93 knots.

Then the time taken $= \frac{AA'}{AF} = \frac{29}{93}$ hr. $=$ 19 minutes.

### 6. Radius of action of an aircraft returning to the same base

(i) The problem is to find (1) how far an aircraft with a given quantity of fuel can fly out over a certain track and have sufficient petrol for the return journey, (2) the courses to steer

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out and home, and (3) the time to turn back. In working out such a problem in practice, a suitable safety margin of fuel must be allowed and this should be done before working out the problem.

(ii) *Example.*—To find the radius of action of an aircraft along a track 080° T. Air speed 140 m.p.h., wind 340° T. at 30 m.p.h. Operational endurance (i.e., allowing safety margin) 6 hours.

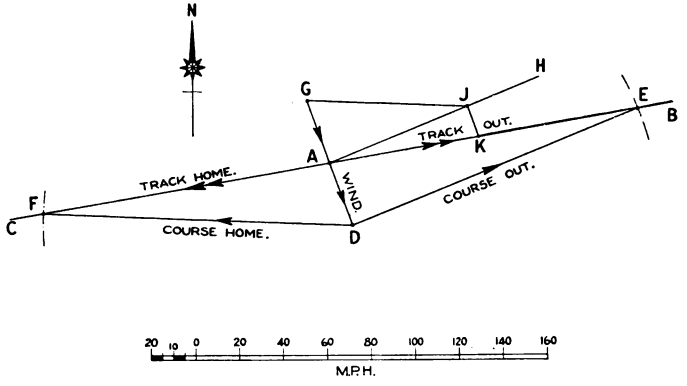


FIG. 49.—Radius of action—returning to the same base.

Let A represent the departure point. (Fig. 49.) From A draw AB, 080° T.: then AB represents the outward track. Produce BA to some point C: then AC represents the homeward track.

From A draw AD, 160° T., 30 m.p.h. to a suitable scale to represent the wind (*down wind*).

With centre D and radius 140 m.p.h. to scale (air speed), describe arcs cutting AB in the point E and AC in the point F. Join DE and DF.

Then DE represents the course out, and DF the course home.

From the diagram the course out is 068° T. and the course home is 272° T. (It should be noticed that, when flying on the reciprocal of any track, if the drift on the outward journey was, say, 12° to starboard, as in the present example, the drift on the return journey must be 12° to port.)

AE represents the ground speed out, and AF the ground speed home. From the diagram the ground speed out is 142 m.p.h. and the ground speed home is 132 m.p.h.

The *radius of action* can be found either by plotting or by the formula given in sub-para. (iv).

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(iii) To find the radius of action by plotting, proceed as follows :—

Draw AG, 340° T. 30 m.p.h. to represent the wind (*up wind*).

From A draw AH parallel to DE, the course out.

From G to AH draw GJ parallel to DF, the course home.

From J to AB draw JK parallel to GD (the wind line).

Then AK gives the radius of action for one hour.

From the diagram, AK represents 68·5 miles.

Then the radius of action for 6 hours equals (68·5 miles × 6) = 411 miles.

(iv) The formula for finding the radius of action is as follows :—

$$R = P \times \frac{(O \times H)}{(O + H)}$$

where R = radius of action in miles.

P = " petrol-hours ".

O = ground speed on outward track.

H = ground speed on homeward track.

The proof of the formula is as follows :—

$\frac{R}{O}$ = the time taken on the outward journey,

and $\frac{R}{H}$ = the time taken on the homeward journey.

$$\text{Then } P = \frac{R}{O} + \frac{R}{H} = \frac{R\,(O + H)}{O \times H}$$

$$\text{whence } R(O + H) = P(O \times H)$$

$$R = P \times \frac{(O \times H)}{(O + H)}$$

In the example in (ii) above :—

$$R = 6 \times \frac{142 \times 132}{142 + 132}$$

= 410 miles (nearly).

The *time to turn* clearly may be found by dividing the radius of action by the outward ground speed.

Thus the time to turn is $\frac{410}{142}$ hr. = 2 hrs. 54 mins.

(v) This problem may also be worked out by C.D.C., as it is only a question of finding the course to steer and the ground speed out and home, given the track required and the wind velocity. As the two problems are not dependent for accuracy one upon the other, this method is quite practicable. To find the radius of action it is first necessary in this case to find the time out and the time home. On the back of the C.D.C. put

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*ground speed out* on the *outer* scale against *ground speed home* on the *inner* scale. Then look round the scale till two numbers are found opposite one another, whose sum equals the " petrol hours " in minutes, i.e. 360 in this case. These two numbers will be found to be 186 on the outer scale and 174 on the inner scale. The number on the inner scale gives the time out in minutes, i.e., 174 minutes or 2 hours 54 minutes. Knowing the ground speed out, and the time, it is simple to work out the radius of action.

### 7. Radius of action of an aircraft returning to a moving base

*Example.*—A seaplane is ordered to leave a carrier, steaming 315° T. at 20 knots, and patrol in a direction 045° T. Air speed 100 knots. Wind 270° T. at 30 knots. The seaplane is to rejoin the carrier in 5 hours. Find the radius of action, the courses to steer out and home, and the time to turn.

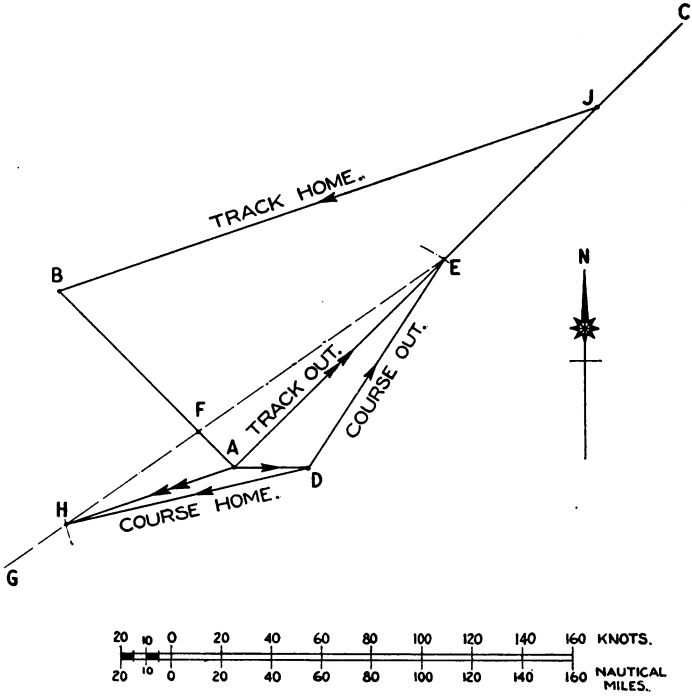


FIG. 50.—Radius of action—returning to a moving base.

Let A be the departure point of both seaplane and carrier. (Fig. 50.)

Lay down B, 100 miles 315° T. from A. This represents the position of the carrier after 5 hours.

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From A draw AC in the direction of the patrol, 045° T.

From A draw AD, 090° T. 30 knots to represent the wind (*down wind*). (*Note.*—In this example it has been found convenient to use equal scales for velocities and distances.)

With D as centre and radius 100 knots to scale (air speed) draw an arc cutting the line AC in the point E. Join DE.

Mark a point F on the line AB so that AF is 20 knots to scale. Join EF and produce to G.

From D with radius 100 knots to scale (air speed) describe an arc cutting EG in the point H. Join DH. We now have :—

DE = the course out = 033° T.
DH = ,, ,, home = 257° T.
AE = ,, track out = 045° T. G/S out, 119 knots.
AH = ,, ,, home = 251° T. G/S home, 71 knots.

The time to turn, and distance of patrol, can only be found by drawing.

From B draw a line parallel to AH, cutting AC in the point J. Then AJ is the distance of patrol, and the time is found by dividing this by the ground speed out.

AJ = 207 miles.

Ground speed out = 119 knots.

Time to turn = $\frac{207}{119}$ = 1 hr. 45 mins. (nearly).

To find the place to turn, it is necessary to draw the track out from the position of A on the map or chart and the reciprocal of the track home from the position of B on the map or chart. Where they meet will be the place to turn.

This problem can be worked by C.D.C., but as there are four successive stages the result is liable to be inaccurate.

### 8. Radius of action of an aircraft returning to a different base

*Example.*—A seaplane stationed at a base A is ordered to patrol in a direction 045° T. from A and return to another base B in 5 hours. B is 100 nautical miles, 315° T. from A. Air speed 100 knots. Wind 270° T. at 30 knots. Find the radius of action.

This problem is essentially the same as the preceding one. The base is regarded as moving from A to B (100 nautical miles) in 5 hours, i.e. at a speed of 20 knots, and the problem is worked in the same way as the example in para. 7 above. (*Note.*—The distance AF is measured on the *speed* scale.)



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**9. A method of search**

(i) When an objective is not seen at the estimated time of arrival and there are no prominent objects by which the position of the aircraft can be checked, as may happen in flights over sea or desert, or when the exact position of the objective is in doubt, some orderly method of search must be employed in order to find it. Unless this is done, finding the objective becomes a matter of pure chance. Different methods of search have been devised, according to individual circumstances: discussion of all the methods is quite outside the scope of this manual. The following method may be found suitable when searching for a ship which is not seen at the expected time of interception, or for an aircraft which has forced landed in the sea or desert when sufficient information is available to enable an approximate estimate to be made of its D.R. position.

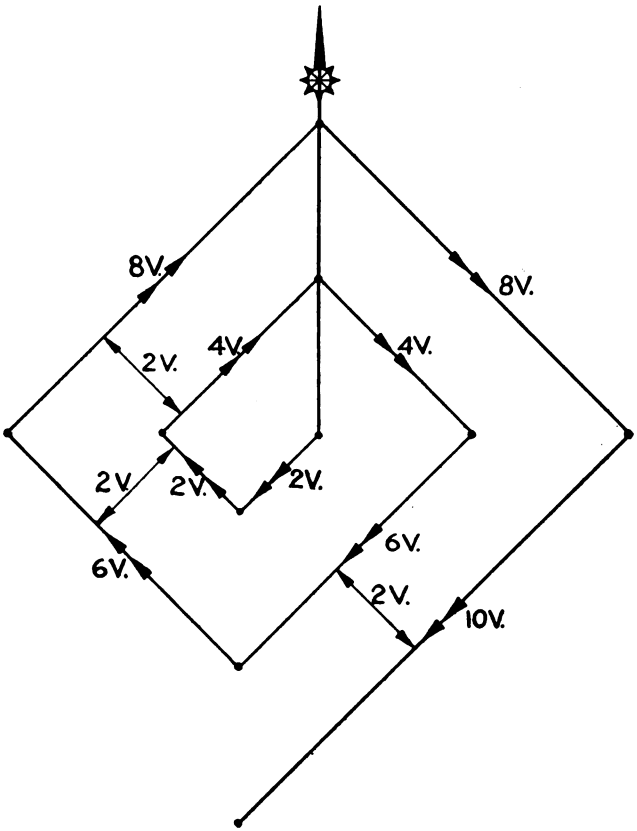


FIG. 51.—Square method of search.

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(ii) This method is known as the *Square Search.* It has been designed to allow the maximum amount of preparation to be done on the ground, with a minimum amount of work in the air, so that the observer shall be free to look for the objective during the search. The aircraft is flown in such a way as to make good the tracks shown in Fig. 51. The tracks are altered periodically through 90 degrees and are so arranged that the distance between them is never more than twice the *visibility distance.* The latter may be defined as the greatest distance from the aircraft at which the objective can be seen and recognised from the height at which the aircraft is flying. It will be evident that an object within the area covered by the search, which does not move during the search, must eventually be seen, since it cannot be at more than visibility distance from one of the marked tracks. In order that the area may be completely covered, the lengths of successive tracks must be 2V, 2V, 4V, 4V, 6V, 6V, 8V, etc., where V is the visibility distance. Flying on northerly courses can be avoided by arranging the tracks in the directions of the quadrantal points, as shown in Fig. 51.

(iii) Figs. 52 and 53 illustrate the following problem :—

A day bomber squadron is ordered to intercept a hostile fleet which was reported to be in a position 50° 00′ N., 01° 50′ W. at 0930 hours, making good 20 knots in a direction 090° T. The squadron is to fly at 5,000 feet. Meteorological forecasts indicate the following conditions : Wind at 5,000 feet, 250° T. 27 knots, visibility 4–6 miles, clouds 3/10 at 3–4,000 feet.

Before leaving the ground the squadron navigator calculates the courses to steer to make good the desired tracks of the search, and the time on each course, making use of the wind velocity and visibility distance indicated in the latest available report. In practice it is advisable to use a visibility distance slightly less than that reported, in order to allow for slight inaccuracies in navigation. It will normally be convenient to commence the search on the quadrantal point nearest to the track to be made good on the way to the interception. If a chart is used, air and wind speeds must be expressed in knots : if a map is used, they should be expressed in m.p.h.

(iv) The results of the ground calculations are tabulated as follows :—

Wind velocity 250° T. 31 m.p.h. = 27 knots. Indicated air speed 150 m.p.h. Computed air speed 162 m.p.h. = 140 knots. V = 4 miles.

| *Track.* | *Distance.* | *Ground Speed.* | *Course.* | *Time.* | *Air Distance.* | *Total Time on Search.* |
|---|---|---|---|---|---|---|
| 225° T. | 8 miles. | 115 kts. | 230° T. | 4 mins. | 9½ miles. | 4 mins. |
| 315° T. | 8 ,, | 127 ,, | 305° T. | 4 ,, | 9½ ,, | 8 ,, |
| 045° T. | 16 ,, | 165 ,, | 040° T. | 6 ,, | 14 ,, | 14 ,, |
| 135° T. | 16 ,, | 149 ,, | 145° T. | 6½ ,, | 15 ,, | 20½ ,, |
| 225° T. | 24 ,, | 115 ,, | 230° T. | 12½ ,, | 29 ,, | 33 ,, |
| etc. | etc. | etc. | etc. | etc. | etc. | etc. |



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(v) The successive courses and air distances are plotted on a convenient part of the map or chart (Fig. 52), using the same scale as that of the map or chart in the area of the search. The centre of this "*still air plot*" is timed as zero, and may for convenience be called "*zero search*", and each change of course is timed as so many minutes after zero.

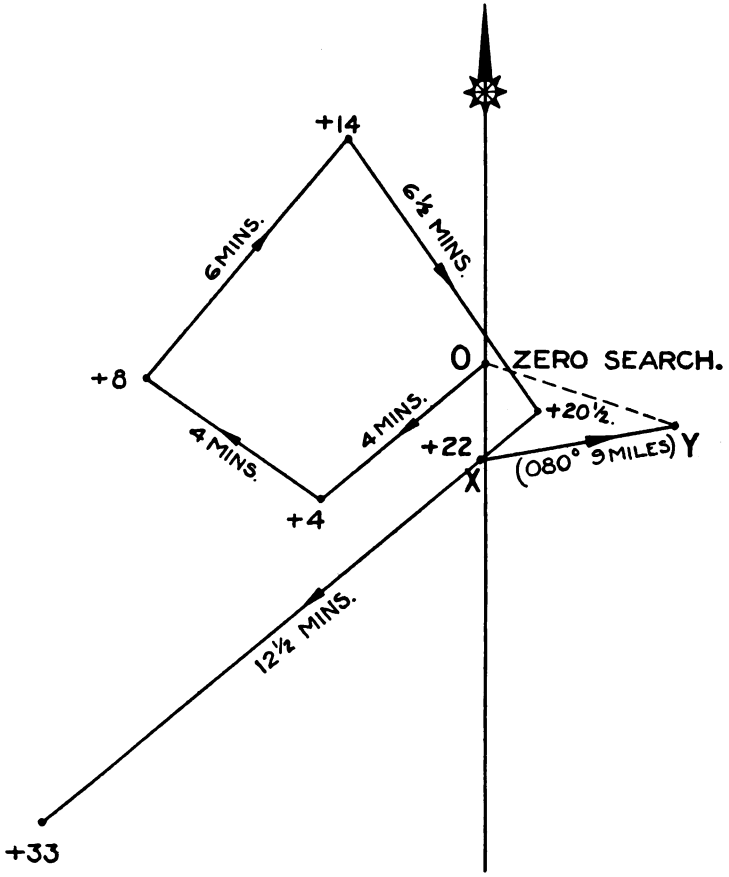


FIG. 52.—Square method of search.

(vi) A chit is made out as follows and handed to the pilot :—

Indicated air speed 150 m.p.h.

| *Course to steer* | *for* |
|---|---|
| 242° M. | 4 mins. |
| 317° M. | 4 ,, |
| 052° M. | 6 ,, |
| 157° M. | 6½ ,, |
| 242° M. | 12½ ,, |

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(vii) The course to steer to intercept the hostile fleet and the estimated time and position of interception are calculated in the usual way (*see* para. 3 of this chapter). The drift should be checked by means of sea markers on the way to the objective and if possible the wind velocity should be determined. If the fleet is not seen at the expected time, the search is at once begun. In the example, the bomber aircraft left the coast at Selsea Bill at 10.00 hours, expecting to meet the hostile fleet at the point " A " (Fig. 53) at 10.24 hours. The fleet was not seen at 10.24 hours. Course was accordingly altered to 242° M. and the search commenced.

(viii) In order to determine the D.R. position of the aircraft when the objective is sighted or the search discontinued, the observer notes on his " still air plot " his air position in relation to " zero search ". He then lays off on the still air plot (in the " down wind " direction) the latest wind velocity found previous to the search, for the time since " zero search ". The bearing and distance from " zero search " of the point thus obtained are laid off from the D.R. position on the chart at the beginning of the search. In the example, the objective was sighted bearing 150° T., 3 miles from the aircraft, at 10.46 hours, 22 minutes after " zero search ". The wind found on the way to the interception was 260° T. 25 knots, and therefore the wind is laid off from the point X (Fig. 52) for 9 miles in the direction 080° T. to the point Y. The bearing and distance of Y from O are laid off from the point A on the chart (Fig. 53), giving the point B as the D.R. position of the aircraft at 10.46 hours. To determine the position of the objective, its bearing and distance from the aircraft must be laid off from B, giving C as the position of the hostile fleet in the example.

(ix) In order to keep the working as simple as possible, no allowance has been made in the example given above for movement of the objective during the search. It is possible that a moving objective may be in the area searched, but may not be seen. Provided that the course and speed of the objective are known with accuracy, and that there is no reason to suppose that either course or speed will be materially altered during the period of the search, allowance for the movement of the objective can be made as follows :—

(*a*) In calculating courses and times for the construction of the " still air plot ", use the " relative " wind instead of the true wind velocity. As described in chapter VIII, para. 11 the relative wind is a velocity compounded of the true wind velocity and the course and speed of the objective. Thus, in the example, the

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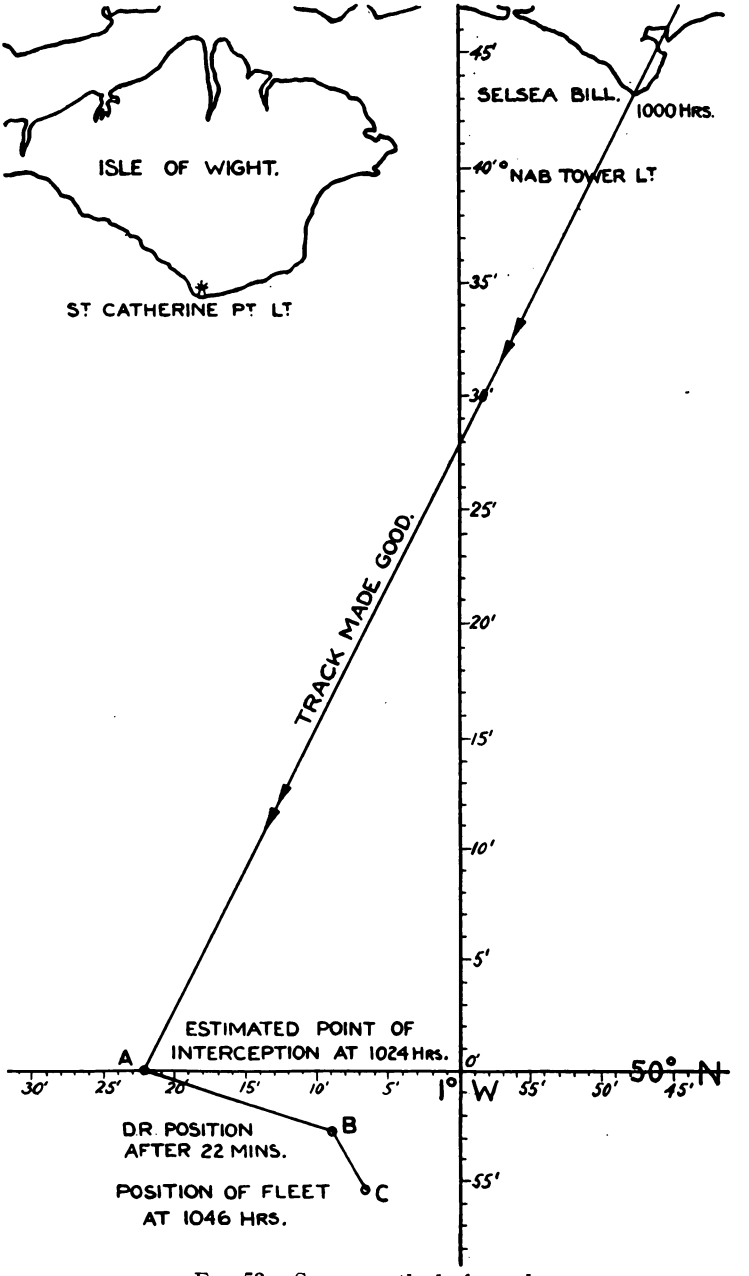


FIG. 53.—Square method of search.

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reported wind was 250° T. 27 knots, and the course and speed of the objective were 090° T. 20 knots. The relative wind is therefore 210° T. 11 knots.

(*b*) In determining the D.R. position of the aircraft at any time during the search from the still air plot constructed as laid down in (*a*) above, use the true wind. The true wind in the example was 260° T. 25 knots.

(x) A disadvantage of the method of search described above is that if the actual wind velocity in the area of the search differs from that used for calculating the courses of the search, the tracks made good will not be those desired. For this reason this method of search cannot be regarded as infallible, but it has the great advantage that the work in the air is reduced to a minimum and the observer is free to look out for the objective.

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## CHAPTER XI.—NAVIGATIONAL INSTRUMENTS

### 1. General remarks

(i) Since successful air navigation is dependent on accurate instruments, all pilots and navigators should be familiar with the principles of the various instruments used. The calibration of navigational instruments is the responsibility of the navigation officer of a unit. (*See* chapter XIX, para. 1.)

(ii) The principle, construction and use of aircraft compasses are considered in detail in chapters XII to XV. In this chapter other instruments used in air navigation are dealt with, as well as some devices which cannot properly be described as instruments. Constructional details and the principle of operation of most navigational instruments are given in A.P. 1275, General Instrument Equipment for Aircraft, Vol. I, and that publication should be read in conjunction with this chapter.

### 2. The air speed indicator

(i) The purpose of the air speed indicator is to measure the speed of an aircraft through the air. The principle of the instrument is as follows:—If a tube with one end closed has the other open and pointing against a current of air, the air pressure inside the tube will be greater than that outside. The value of this excess of pressure in the tube depends upon the velocity of the air current and the density of the air. It is clear, therefore, that if the tube is kept facing into the air flow and a suitable pressure gauge is connected to the closed end, the gauge can be calibrated to measure the speed of the air relative to the tube. (The relation between the speed of the air flow and the pressure only holds good if the inclination of the tube to the air flow is zero. The error for angles of inclination of less than 10° is, however, very small.)

(ii) In the air speed indicator the open-ended tube, known as the *pitot head*, is mounted on the aircraft in a position where it is clear of the slipstream from the airscrew, usually on an inter-plane strut, and is connected to a suitable form of pressure gauge in the cockpit by means of metal tubing with rubber-sealed joints. The instrument has to measure the difference between the pressure inside this tube, due to the motion of the aircraft through the air, and that of the surrounding still air. Inside the cockpit of an aircraft in flight, the air flow generally produces a region of low air pressure, the extent of which depends on so many factors that it is

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essential for the instrument to be independent of it. For this reason the low pressure side of the instrument is connected to a second tube, called the *static-pressure tube*, which is led to a point adjacent to the pitot tube. The static-pressure tube is closed at the end which faces into the air flow, but is pierced by numerous small radial holes near that end (*see* Fig. 54). The pitot and static-pressure heads are mounted on a bracket and form a unit which is called the *pressure head*.

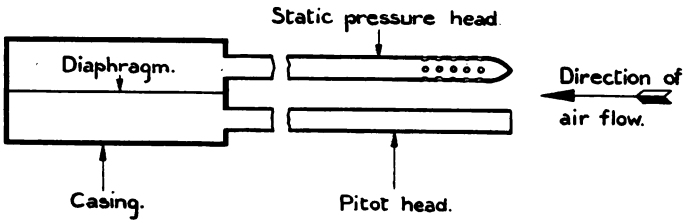
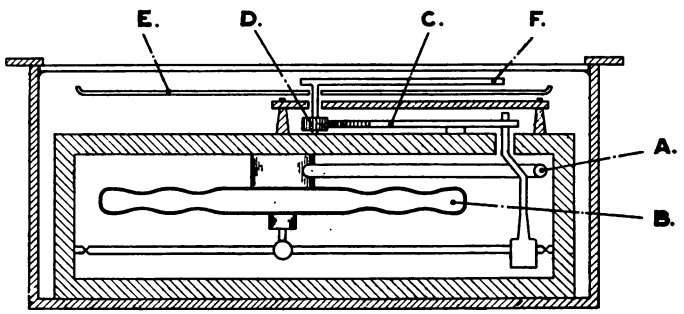



FIG. 54.—Principle of the air speed indicator.

(iii) There are two types of dashboard instrument. In the first the pitot and static-pressure tubes are led to opposite sides of a flexible diaphragm mounted in an airtight case, as shown diagrammatically in Fig. 54. In the second type the static-pressure tube is connected to an airtight container in which is mounted a sensitive expansion chamber or capsule made of thin corrugated metal, one side of which is fixed and the other free to move. The pitot tube is led to the interior of this capsule (*see* Fig. 54A). When pressure causes distension of the diaphragm (in the first type) or the metal capsule (in




A. PRESSURE INLET.
B. EXPANSION CHAMBER.
C. QUADRANT.
D. PINION.
E. DIAL.
F. POINTER.

FIG. 54A.—Air speed indicator—metal capsule type

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the second) the movement is magnified and transferred by a suitable system of linkage to a pointer registering against a scale which may be calibrated in miles per hour or knots.

The various types of air speed indicators in use in the Royal Air Force are described in A.P. 1275, section 1, chapter III.

(iv) It has been stated in (i) above that the pressure difference measured by the instrument depends on the density of the air through which the aircraft is passing. The density at any point depends on the atmospheric pressure and the temperature, which are variable factors, and consequently a standard value for the density has to be assumed in order that the air speed indicator may be calibrated. Air speed indicators in use in the Royal Air Force are calibrated to read correctly at a density corresponding to normal sea-level pressure (1013·2 millibars) and a temperature of 15° Centigrade. With increase of height the density becomes less, and therefore an air speed indicator will normally under-read at heights above sea level. Approximate correction may be made by adding 1·75 per cent. of the indicated air speed for every 1,000 feet of height above sea level. More accurate corrections, allowing for the actual temperature and pressure, are obtained by the height and air computer (*see* para. 6).

(v) Air speed indicators are liable to a permanent error, known as *position error*, which is due to the pressure head being situated in an air flow which is disturbed by eddies set up in the neighbourhood of the wings, struts, etc. The amount of the error depends on the air speed, but is the same for all aircraft of a given type. The error is reduced as far as possible by careful choice of the position of the pressure head, and its value at different air speeds is determined during trials of a new type of aircraft. A table of corrections is made up which is published in the air publication dealing with the type of aircraft in question.

(vi) The pressure head and connecting tubes must be kept clean and in good condition. An obstruction in the pitot tube or a leak or dent in the connecting tubes will cause low readings. If the small holes in the static-pressure tube become blocked, the instrument may read accurately at ground level but will read low, as a rule, above ground level. It is most important that the connecting tubes should be free from leaks.

Further details concerning the installation and maintenance of air speed indicators will be found in A.P. 1275, section 1, chapter III.

**3. Calibration of air speed indicators**

(i) The calibration of air speed indicators should be checked whenever their accuracy is in doubt, or in any case during the periods of overhaul of the aircraft. The construction and use

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of calibrators are described in A.P. 1275, section 6, chapter IV. The principle is to use a water manometer or U-tube, the scales being marked to read directly in air speeds. Air pressure is applied simultaneously to the U-tube and the indicator under test and a comparison is made between the readings.

(ii) If no calibrator is available, an instrument thought to be faulty may be calibrated by comparison with a reliable air speed indicator. The two instruments should be connected with rubber tubing, as shown in Fig. 54B. Both static nipples (marked " S ") are open to the atmosphere. By rolling up the tubing at " A," equal pressure is applied to both instruments through the pressure nipples (marked " P "). A comparison of the readings will show any error which may exist.

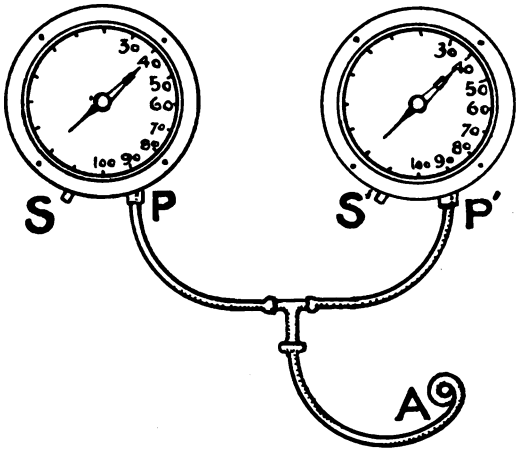


FIG. 54B.—Calibration by second air speed indicator.

(iii) The total error of the instrument at various air speeds should be tabulated on a small card placed in the aircraft alongside the indicator. The total error is the combination of the instrumental error found by calibration and the position error. The following extract from a typical calibration shows how the total error is found :—

| *True Air Speed.* | *Instrument Reading.* | *Error.* | *Position Error.* | *Total Error.* | *Indicated Air Speed.* |
|---|---|---|---|---|---|
| 110 | 108 | +2 | +3 | +5 | 105 |

The figures in the first and final columns would be entered on the correction card placed in the aircraft.

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## 4. The altimeter

(i) The altimeter is an instrument for indicating the height of the aircraft in which it is installed. The instrument is a special form of aneroid barometer (a barometer without liquid) which measures the pressure of the atmosphere. The atmospheric pressure at any point is due to the weight of air above, which decreases as the height above the ground is increased, and consequently the instrument can be calibrated to read in terms of height.

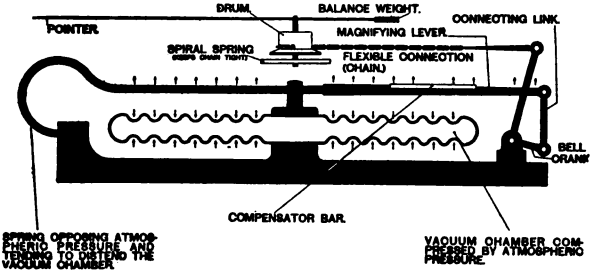


FIG. 55.—Aneroid altimeter.

(ii) The construction of the altimeter is shown in Fig. 55. The instrument contains a round flat vacuum box made of thin corrugated metal, from which the air has been exhausted. One side of this box is attached to the outer case of the instrument. This case is not airtight, so that the pressure inside it is the same as that of the surrounding air. The pressure of the atmosphere tends to make the box collapse, but it is prevented from doing so by a spring to which its free side is attached. Decrease of atmospheric pressure reduces the load on the box and allows the spring to extend. The resulting movement, which is very small, is magnified by a system of connecting links and transferred to a pointer registering against a scale which is graduated in terms of height. Incorporated in the instrument is a compensator bar composed partly of steel and partly of brass which by reason of the different expansion of these metals counteracts the effects of temperature changes on the mechanism of the instrument.

The various types of altimeters used in the Royal Air Force are described in A.P. 1275, section 4, chapter I.

(iii) The relation between pressure and height is not a constant one, but depends upon the temperature, not only at the given height but also at all points between the height and the ground, and upon the pressure at ground level, which factors change according to the meteorological conditions.

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In order to calibrate an altimeter it is necessary to assume certain standard conditions of the atmosphere: corrections can then be made to the altimeter readings to allow for the conditions actually observed.

(iv) There are two calibration laws in use in this country, known as the *Isothermal* and *I.C.A.N.* laws. All altimeters at present in use in the Royal Air Force, with the exception of a few instruments used for special purposes, are calibrated according to the isothermal law, which is based on the assumption that the temperature at all heights has the constant value of 10° Centigrade.

The I.C.A.N. law is used only for calibrating certain altimeters used for special test purposes, and will not be considered here. Details of this calibration law will be found in A.P. 1275, section 4, chapter I.

(v) The isothermal law assumes that the ground pressure has a constant value of 1013·2 millibars. In practice the ground pressure changes according to the meteorological conditions, and therefore the reading of an altimeter at ground level would vary from day to day in exactly the same way as that of any other barometer. For this reason the dial of the instrument is made adjustable: by turning a small milled knob the altimeter may be set, either to zero or to the height of the aerodrome above sea level, before a flight is commenced (*see* chapter IX, para. 3 (iii)). Since the scale of adjustable dial altimeters is evenly divided, the instrument will then automatically allow for the fact that the pressure corresponding to zero on the scale differs from the standard ground pressure. It should be remembered, however, that the ground pressure varies from place to place, so that the altimeter may give incorrect readings on a long flight (*see* chapter XVII, para. 4).

(vi) The isothermal law assumes that the temperature of the atmosphere remains constant at 10° C. (50° Fahrenheit). Since in practice the temperature generally falls as height is increased (*see* chapter XVII, para. 5) corrections to the altimeter readings are required: these may be large at high altitudes. The corrections are calculated by means of the height and air speed computer (*see* para. 6).

(vii) The altimeter requires little attention. Although the mechanism is delicate the instrument will continue to work accurately for long periods, so long as it is preserved from shocks or excessive vibration. A leak in the vacuum box or damage to the mechanism will render the altimeter unserviceable. A faulty instrument should be replaced and no attempt made to repair it within a unit.

(viii) Owing to the imperfect elasticity of the vacuum box and the spring, the altimeter does not immediately record

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changes of height. If the height is changed suddenly by 1,000 feet the pointer will lag and it may be nearly one minute before the correct height is indicated. On account of this lag the altimeter may read low when ascending and high when descending.

**5. Calibration of altimeters**

(i) Periodically, or at any time when its accuracy is in doubt, the calibration of an altimeter must be checked. This is done by comparing its readings, when subjected to different pressures, with those either of a standard mercury barometer or of an altimeter which is known to be accurate. The standard mercury barometer supplied for the calibration of altimeters is the Portable Mercury Barometer, Mark I, which is used in conjunction with the Portable Altimeter Calibrator, Mark I. Full details of the construction of these instruments and of the methods of calibrating altimeters will be found in A.P. 1275, section 6, chapters I and II.

(ii) When an altimeter is calibrated, its readings should be checked every 1,000 feet up to the " ceiling " of the aircraft in which it is installed. The readings should not be taken at a quicker rate than 1,000 feet every minute, owing to the imperfect elasticity of the mechanism of the instrument. In readings below 5,000 feet an error of $\pm$200 feet, between 5,000 and 10,000 feet an error of $\pm$300 feet, and above 10,000 feet an error of $\pm$400 feet may be tolerated without discarding the instrument. A card showing the amount by which the altimeter reads high or low at various heights should be pasted on or near the instrument.

**6. The Height and Air Speed Computer**

(i) Altimeters and air speed indicators are calibrated according to laws which make certain assumptions regarding the physical properties of the atmosphere. Under conditions which differ from those assumed, these instruments will give incorrect readings. The Computer, height and air speed, Mark I, has been designed to calculate the necessary corrections. The principle, construction and use of this instrument are described in A.P. 1275, section 10, chapter I.

(ii) It was stated in para. 2 (iv) that the computer makes the necessary corrections for both temperature and pressure to the readings of an air speed indicator. The correction for temperature is obtained by setting on the computer the temperature indicated by a transmitting or strut thermometer fitted to the aircraft. The computation for pressure is obtained by setting the altimeter height, with a correction for the observed ground pressure : this correction is necessary since

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the altimeter was set to read zero at a ground pressure differing from the standard value. It will be observed that the ground pressure setting has no effect on the computation of height.

### 7. The Course and Distance Calculator

(i) The course and distance calculator is an instrument designed to give an approximate solution of the triangle of velocities simply and rapidly.

(ii) The course and distance calculator, 9-inch, Mark I, consists of :—

(*a*) An outer ring of brass graduated on its face every two degrees from 0° to 360°.

(*b*) A central ring and disc marked with an arrow and 5 mile squares representing a total diameter of 240 miles, which can be revolved within the outer ring.

(*c*) Two radial arms pivoted at the centre of the disc and marked from 0 to 110 miles on the same scale as the disc. Each arm carries a movable pointer. There is a milled head screw in the centre for locking the two arms when necessary. The two arms are identical, but are marked " A " and " B " for reference.

(*d*) The time and distance scale, which is a simple logarithmic slide rule marked on the back of the instrument. It comprises an inner time scale and an outer distance scale which can be rotated in relation to one another.

(iii) The principle of the course and distance calculator is dealt with in relation to actual navigation problems in chapter V.

### 8. The Course and Speed Calculator

This instrument is under development and it is intended that it shall replace the course and distance calculator. Details of its construction and methods of use will be given in A.P. 1275 when the instrument is issued for service.

### 9. The Course and Wind Calculator, type D

This instrument solves problems involving the triangle of velocities by the same methods as the calculator already described. In addition, a fourth vector, representing datum ship course and speed, is introduced, so that problems involving a fourth vector can be solved directly without the necessity of plotting velocity diagrams.

The construction and use of the instrument are described in A.P. 1275, section 9. chapter V.

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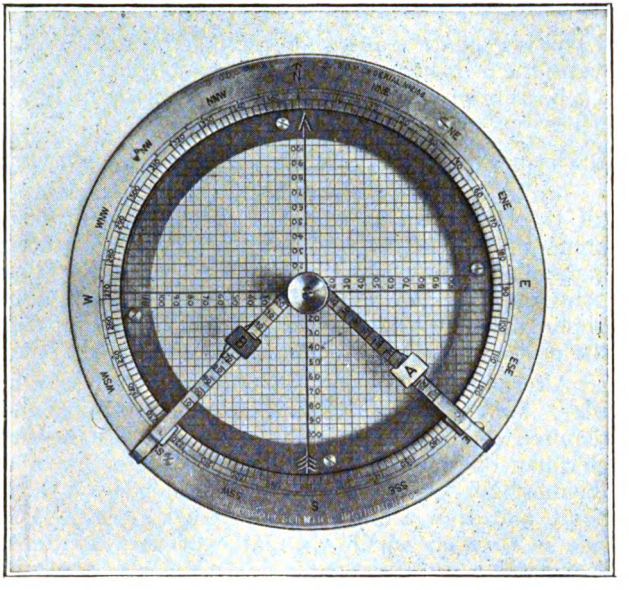

FIG. 56.—9-in. Mark I, Course and Distance Calculator.

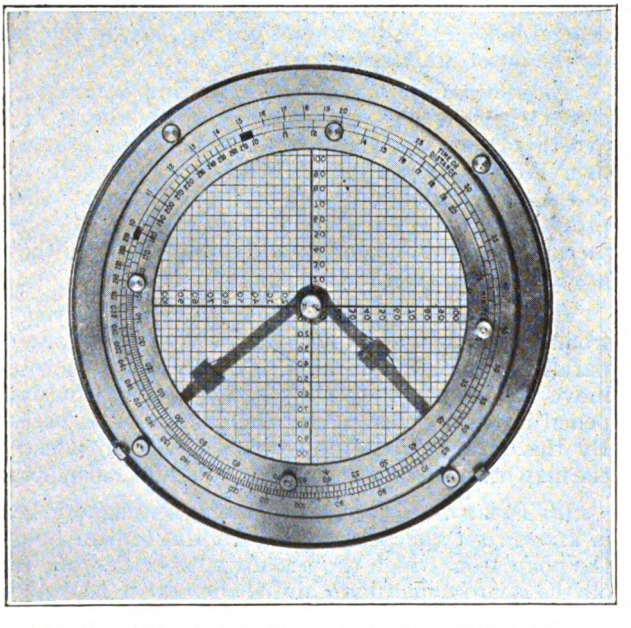

FIG. 57.—9-in. Mark I, Course and Distance Calculator.



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**10. The Douglas protractor**

(i) This is a square, transparent celluloid protractor designed to obviate the use of the parallel rule when taking off or laying down a bearing on a map or chart. It is made in two sizes, ten inches square and five inches square.

(ii) The protractor may be used in the following ways :—

(*a*) To lay down a course or bearing from a given point, set the protractor so that the central hole is over the point and the line joining the centre to the zero graduation is parallel to the nearest meridian or grid line. Mark the point opposite the required graduation (remembering to apply the grid deviation if a grid line is used for aligning the protractor) and join this point to the given point.

Alternatively, the left side may be used as a ruling edge. Set the protractor so that the central hole and the required graduation in *italic* figures lie on the nearest meridian or grid line. Slide the protractor up or down the meridian or grid line until the left edge is on the given point, and draw a line along this edge. (*Note.*—The left side is that on which the name of the instrument is engraved.)

(*b*) To measure a course or bearing from a line drawn on the map or chart, align the protractor on the nearest meridian or grid line and slide it up or down until the central hole lies on the line of bearing. Read the bearing on the outer graduations.

Alternatively, to take off a bearing between points close together, e.g. the bearing of Netheravon from Worthy Down, set the protractor with the central hole over Worthy Down and with the line joining the centre to the zero graduation lying over Netheravon. Slide the protractor until the central hole is over the nearest meridian or grid line, and read the bearing from the italic graduations (*see* Fig. 58).

(*c*) To use as a parallel rule or to take a bearing to or from a compass rose, align the protractor by one of its parallel lines on the bearing or on the compass rose and move the protractor to the position required by drawing pencil lines on either side of the protractor as necessary. By this means a bearing can be moved anywhere over the map or chart with no chance of unknown displacement.

(*d*) To lay off a true bearing when the magnetic bearing is known, set the protractor with the central hole over the point from which the bearing is to be laid off, align it on the nearest meridian, and then treat it as a movable compass card. For example, suppose the magnetic

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bearing to be 340° and the variation 10° west. Align the protractor as described and then move it 10° anti-clockwise. Mark the point opposite the 340° graduation and join it to the central point.

By a similar means bearings laid down on a map or chart may be measured as magnetic, and bearings or tracks measured relative to the grid lines may be converted to true.

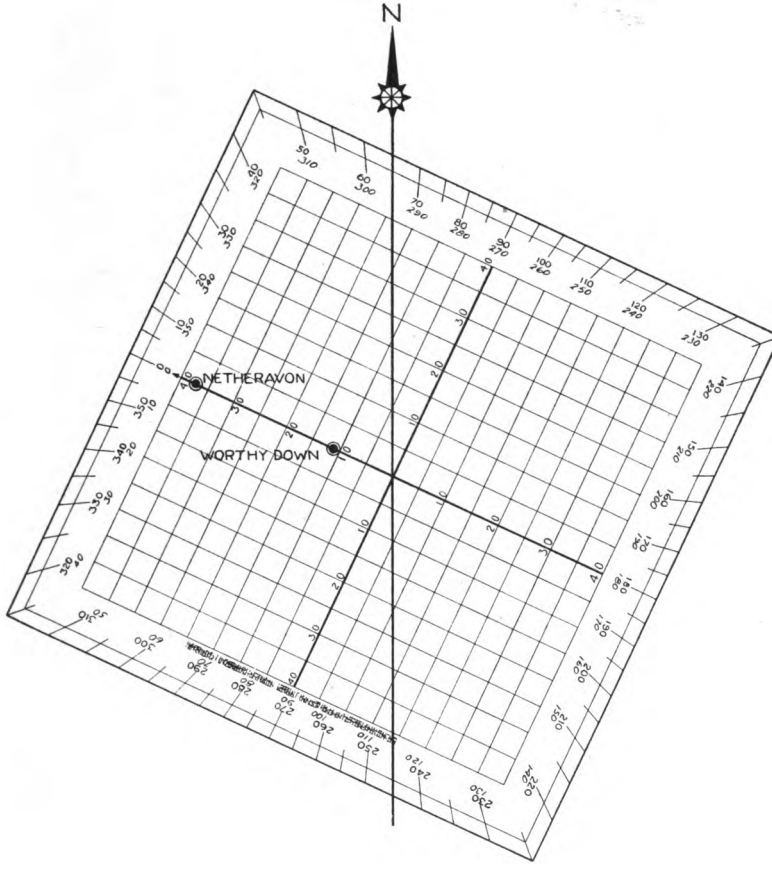


FIG. 58.—Douglas protractor.

## 11. The Chart Board, type "B"

The instrument consists of a square wooden board upon which a sheet of celluloid is fixed so that folded maps or charts may be held flat without possibility of movement. The celluloid sheet is secured by hinges and brass clips. The



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instrument is made in two sizes, seventeen inches square and fourteen inches square. A celluloid protractor is attached to movable arms which may be clamped anywhere along either side of the chart board. It may be necessary to move the clamp occasionally in order to work on the corners of the board. Chinagraph pencils are issued with which to mark the celluloid sheet : the marks can easily be erased.

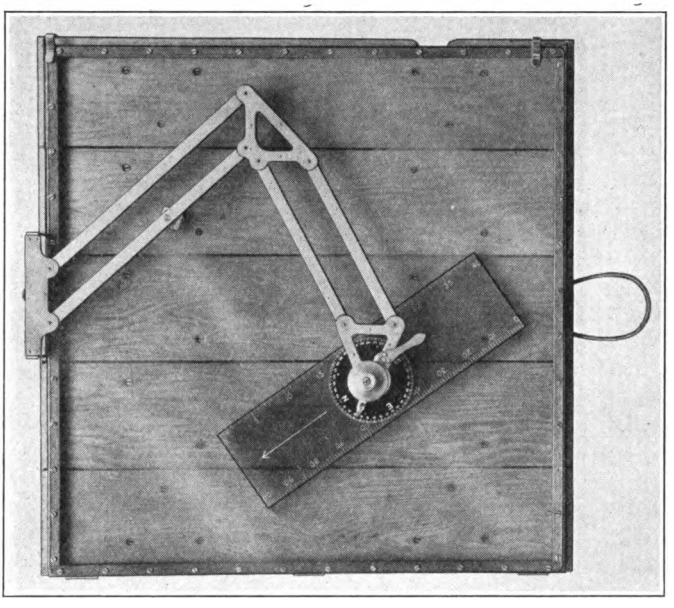

FIG. 59.—Chart board, Type B.

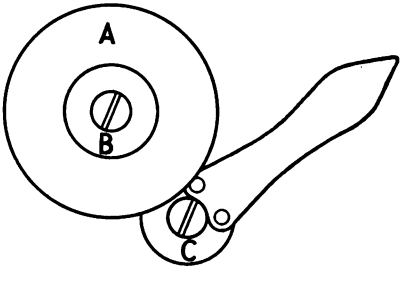


FIG. 59A.—Chart board, Type B.

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The protractor may be used to lay down or take off true or magnetic bearings. It is graduated along one edge in inches and tenths of an inch to show miles on a scale of 10 miles to the inch, and along the other edge in quarter-inches to show miles on a scale of 4 miles to the inch. The protractor rotates about its centre, and above it are two milled head screws " A " and " B " and a clamp " C " (*see* Fig. 59A). By the large milled head screw " A " the protractor is turned until one edge is coincident with the true or magnetic meridian as may be desired. The clamp " C " is eased off, the metal pointer set at 0°, and " C " is clamped. Bearings may now be taken from the map or chart by aligning the edge of the protractor in the required direction and reading off the bearing indicated by the pointer. To use the protractor as a parallel rule, set the required direction to the pointer and clamp screw " B." The bearing may now be laid down anywhere on the map or chart.

A rubber loop is provided to hold the protractor when it is not in use and so prevent it from being damaged.

## 12. The Course Setting Bomb Sight

(i) Although its primary purpose is for use as a bomb sight, this instrument is of considerable use for air navigation. It provides accurate methods of measuring the drift and ground speed, and of finding the wind velocity.

(ii) The bomb sights at present in general use in the Royal Air Force are the Marks VIIA, VIIB and VIIC. Their principal characteristics are as follows :—

| | | *Air Speed Range.* | *Wind Speed Range.* |
|---|---|---|---|
| Mark VIIA. | High altitude. | 70–180 m.p.h. | 0–60 m.p.h. |
| Mark VIIB. | Low altitude. | 47–120 knots. | 0–40 knots. |
| Mark VIIC. | High altitude. | 60–156 knots. | 0–50 knots. |

Constructional details of these sights are given in Air Publication 1243, Armament Training Manual, chapter 8.

(iii) The instrument may be used as a course and distance calculator : the air speed bar, the drift bar and the wind bar forming the three sides of the triangle of velocities. In the Mark VII series of bomb sights a fourth vector, intended for use when bombing moving targets, is included, and the bomb sight may therefore be used in the same way as the course and wind calculator, type D, for solving problems involving a fourth vector. For normal use for navigational purposes, the fourth vector should be set to zero.

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(iv) *To find the drift.*—When the aircraft is on a steady course, level the bomb sight by means of the levelling screws on the bracket on which the instrument is mounted. Set the computed airspeed by turning the knob AS (Fig. 60). Adjust the drift bar, by rotating either the screw CB or the wind screw H, until objects appear to pass down the drift wires. If the wind bar is kept approximately at right angles to the air speed bar, the screw H provides a coarse adjustment and the screw CB a fine adjustment. The observer's head must be

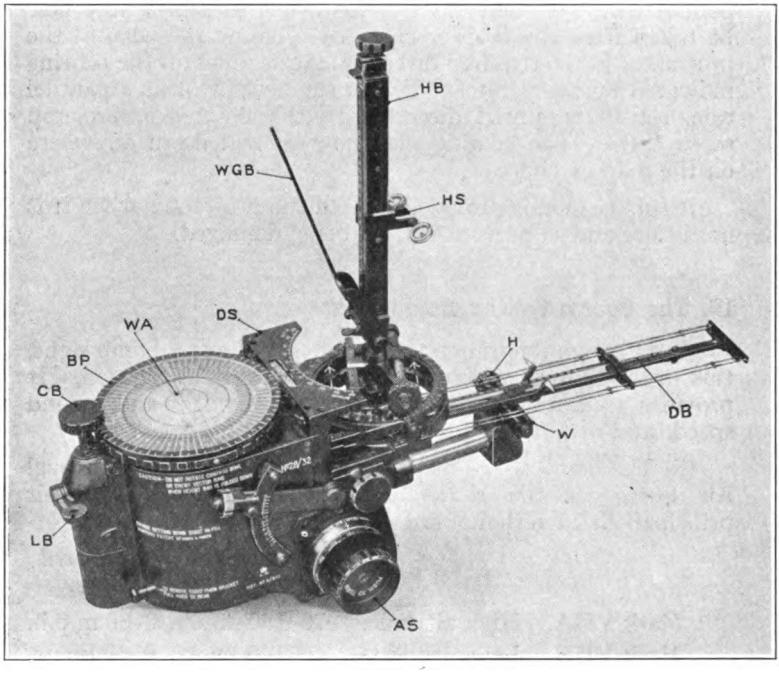


FIG. 60.—Course setting bomb sight, mark VIIA.

kept steady when drift is being measured : it is advisable to view the ground and the drift wires through the backsight on the height bar. To obtain the angle of drift, fold down the wind guage bar WGB and read the drift on the scale DS. The track made good may be obtained by applying the angle of drift to the course steered (*see* chapter VII, para. 3 (iii)).

(v) *To find the ground speed.*—Level the bomb sight and set the computed air speed. Set the terminal velocity to infinity in order to keep the height bar vertical. Set the slider to the height bar (HS in Fig. 60) to the computed height *above the ground* on the red scale. On the Marks

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VIIA and C, the height range is 6,000–14,500 feet; in the Mark VIIB, 5,000–13,500 feet. Adjust for drift until objects pass down the drift wires. With a stop-watch time the passage of an object from one bead on the drift wires to the next, looking through the backsight on the height bar. It is advisable to time several objects down the drift wires and to take the mean of the readings.

The distance between consecutive beads, as viewed through the sight, is equivalent to one statute mile (Mark VIIA) or one nautical mile (Marks VIIB and C) on the ground, so that the time in seconds to cover this distance is equal to the number of minutes to cover 60 miles. For example, if the measured time were 30 seconds, the aircraft would take 30 minutes to cover 60 miles and its ground speed would therefore be 120 m.p.h. (or knots). There are two scales on the drift bar, one being a scale of ground speed, the other showing the corresponding time in minutes to cover 60 miles (i.e., the observed time in seconds).

(vi) *To find the wind velocity by the* 90*-degree method.*—Level the bomb sight. Set the computed air speed and rotate the compass bowl by means of the screw CB until the tail of the wind arrow WA is opposite zero on the drift scale. Fly directly up-wind, altering course as necessary until no drift is discernible. Unclamp the bearing plate BP by operating the clamp LB, so that it is free to move without moving the wind arrow, and turn it until the grid wires are parallel to the compass needle, with the north (" *red* ") end of the compass needle registering with the red zero mark on the bearing plate. Clamp the bearing plate. The direction of the wind may now be read off against the tail of the wind arrow. (To obtain the true wind direction, apply the deviation of the bomb sight compass *on the course steered*, and the variation.) Now, turn the aircraft through about 90 degrees to port or starboard, fly on a steady course, and rotate the compass bowl by turning the screw CB until the red zero mark on the bearing plate registers with the north end of the compass needle (i.e., set " *red on red* "). Adjust the wind bar W by means of the screw H until objects on the ground appear to pass down the drift wires, and read the wind speed on the wind scale. (It will be noticed that keeping " red on red " maintains the wind bar and wind arrow always parallel to the wind direction.)

(vii) *To find the wind velocity by the " 3-course " method.*—Level the bomb sight and set the computed air speed. Fly on any steady course and adjust for drift. Unclamp the bearing plate, set " red on red ", fold down the wind gauge bar, and draw a line along the bevelled edge of the bar on the glass top of the bearing plate with a paint (chinagraph) pencil. Alter course at least 50 degrees (preferably about 60 degrees) to port

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or starboard and repeat the series of operations. Alter course a further 60 degrees, or about 120 degrees in the opposite direction, and repeat the series of operations again. The three lines drawn on the bearing plate will intersect, forming a small " cocked hat ". The more accurately the above operations have been performed, the smaller will be the cocked hat. Estimate the centre of the cocked hat (called the " *wind point* ") and turn the bearing plate until this point is directly over the tail of the wind arrow. Clamp the bearing plate. The wind direction can now be read opposite the tail of the wind arrow. The wind speed may be found as follows :—Turn the compass bowl until the wind arrow is approximately at right angles to the air speed bar, fold down the wind gauge bar, and adjust the wind speed screw until the bevelled edge of the wind gauge bar passes through the wind point. The wind speed can now be read on the wind speed scale. (It will be noticed that this method is the same in principle as that described in chapter VIII, para. 3.)

(viii) *To find the wind velocity by the " timing bead " method.* —This method consists simply of finding the drift and ground speed as described in (iv) and (v) above, and using the bomb sight to solve mechanically the triangle of velocities. Thus, suppose the time taken for an object to travel from one bead to the next is 30 seconds and the drift 12 degrees to port. The wind speed screw and the compass bowl are adjusted together until the drift bar scale reads 30 on the time scale and 120 m.p.h. on the speed scale, while the drift reading remains unaltered at 12° P. This operation requires practice before it can be performed quickly. The wind speed is read from the wind speed scale and the wind direction is found by setting " red on red " and reading the graduation opposite the tail of the wind arrow.

This method is considerably simplified by a modified form of wind gauge bar which is now fitted to all Mark VII bomb sights. This consists of a narrow plate on which are described several numbered curves and along which slides a cursor graduated in air speed. After an object has been timed between beads, the wind gauge bar should be lowered on to the bearing plate and the latter rotated to bring " red on red ", without rotating the compass bowl and to altering the drift angle set. The cursor on the wind gauge bar is now adjusted until the appropriate air speed graduation on the cursor coincides with the curve on the wind gauge bar which bears the figure corresponding to the time determined in seconds. Interpolation may be necessary. The glass top of the bearing plate should be marked with a paint pencil through the small ring attached to the cursor. This point is the wind point. The wind velocity may now be found by setting the wind point over the tail of the wind arrow and proceeding as described in (vii) above.

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**13. The Course and Drift Indicator (bearing plate)**

(i) The pattern described below is the bearing plate with ground speed sights 6-inch, Mark I (Figs. 61 and 62). The instrument consists of three concentric rings which can be turned relatively to each other. The middle ring constitutes the base plate and is furnished with a bracket which will fit into a metal shoe mounted on the aircraft. The inner ring is marked in graduations of 1 degree from 0 to 360. The outer ring carries a hinged height scale marked from 500 to 2,500 feet, fore and back sights, and two diametrical celluloid lines.

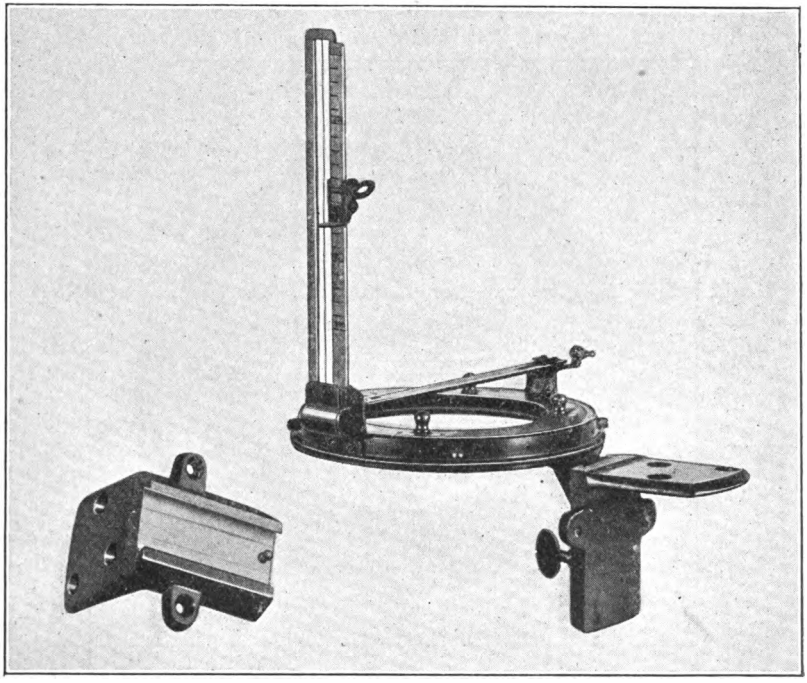

FIG. 61.—Course and drift indicator (bearing plate).

Two metal shoes are supplied for fixing on the aircraft in order that the instrument may be used on either side. The bearing plate must always be fixed in the aircraft with the lubber lines pointing parallel to the fore and aft axis of the aircraft.

(ii) The instrument has three uses, (*a*) taking bearings, (*b*) indicating drift and (*c*) obtaining ground speed.

(iii) A magnetic bearing of an object may be taken in the following way. Set the inner dial with the graduation representing the magnetic course of the craft opposite the lubber

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line. Turn the sighting arm until the object is seen in the line of sight ; the magnetic bearing can be read on the inner dial. Alternatively, the inner dial may be set to zero and a bearing taken relative to the head of the aircraft. A magnetic bearing may be obtained from this by adding the angle indicated on the bearing plate to the magnetic course of the aircraft at the instant the bearing was taken. This latter method will generally be the more accurate as it is easier for the pilot, by means of a simple signal, to read the course of the aircraft at the instant the observer takes the bearing, than it is for the observer to take the bearing at the instant the aircraft is on its course, as indicated by the pilot.

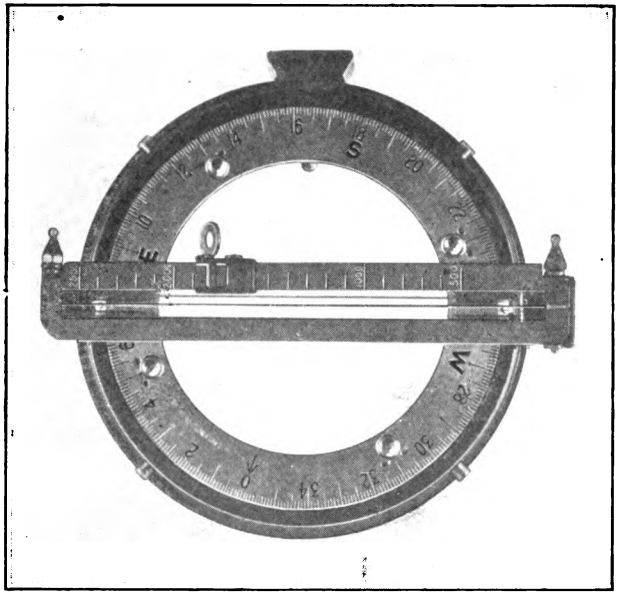

FIG. 62.—Course and drift indicator (bearing plate).

(iv) The instrument can also be used for measuring angles. When used for this purpose the inner dial must be set to 0° and the bearing plate used as when taking bearings. Then the angle between any two objects will be the difference in degrees between the two readings on the graduated arc obtained by sighting on the objects.

(v) To use as a drift indicator, set the inner dial to zero, look vertically downwards through the open centre and turn the outer dial until objects on the ground or surface of the sea appear to pass along the diametrical lines from end to

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end. Read off the difference in angle to starboard or port between the zero of the instrument and the central diametrical line. This gives the angle of drift in degrees.

(vi) To obtain ground speed, set the sight bar on the height scale to the height of the aircraft *above the ground over which the aircraft is flying*. Align the eye hole sight with the fore sight on any object which lies in the actual track and when alignment occurs start a stop-watch. When the same object is vertically below the observer, as indicated by the rear sight coming into alignment between the eye hole sight and the object, stop the watch. The aircraft has then passed over a certain distance in the time indicated by the stop watch and from this the ground speed can be calculated. The distance referred to may be half a statute mile or half a sea mile, and this is stated on the height scale. The calculation to arrive at the ground speed can be made simply by means of the time and distance scales on the course and distance calculator.

## 14. The Tail Drift Sight, Mark IV

The tail drift sight is used for taking drift readings on an object over which the aircraft has passed. The object is followed astern through the optical system of the sight, the drift angle being read from a scale. In the tail drift sight Mark IV it is not necessary for the aircraft to pass directly over the object, as a correction for the initial displacement of the object is automatically applied when the sight is used. Details of the construction and use of the tail drift sight Mark IV will be found in A.P. 1275, section 9, chapter I.

## 15. Drift markings

(i) The approximate angle of drift can be observed by means of marks on the lower main planes. Although absolute accuracy is not to be expected, the method is useful to the pilot-navigator who cannot conveniently use instruments for determining drift. The method of laying out wing markings is described below.

(ii) The aircraft should be placed in flying position on a level concrete floor and carefully aligned so that its longitudinal axis lies exactly over a straight line AB (Fig. 63) marked on the floor by chalk, a stretched tape, or other suitable means. A simple form of back sight ($S_1$), such as a small ring or short rod, is fitted on the outside of the fuselage, and a fore sight (F) in the form of a small clip or band is fitted to a front flying wire. These sights must be so placed that the pilot can sight along them without moving his head from its normal position, and that the point on the ground on which they are aligned (P)

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is well forward of the leading edge of the lower main plane and a few feet from the line AB. From the point P a line PQ is drawn parallel to AB, and lines are then drawn from P on both sides of PQ making angles of 5°, 10°, 15°, 20°, etc., with PQ. (In Fig. 63 these are, for simplicity, only shown at 10° intervals.) The lower main plane is marked at the points where these lines appear to cut the leading edge, as seen by the pilot through a second back sight $S_2$ fitted slightly behind $S_1$. The marks should consist of painted lines about four inches long. It should be noted that marks to the right of the zero mark indicate port drift, and marks to the left indicate starboard drift.

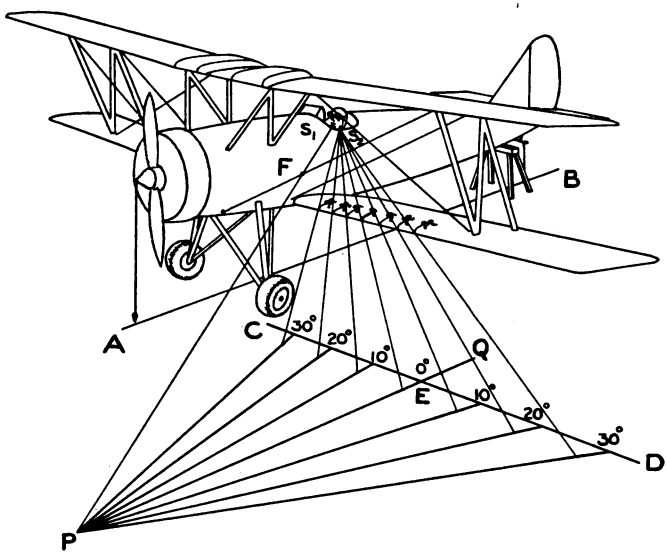


FIG. 63.—Drift markings on main planes.

The following method may be found convenient for laying off the angles from P. A point E is chosen on PQ and a line CD is drawn through E at right angles to PQ. A scale of tangents of the angles 5°, 10°, 15°, etc., is constructed along EC and ED and lines are drawn from P to each of the points so determined. A suitable position for the point E is 10 feet from P. The distances to be laid off from E along EC and ED will then be as follows :—

| | |
|---|---|
| 5° .. .. .. | 10½ in. |
| 10° .. .. .. | 1 ft. 9 in. |
| 15° .. .. .. | 2 ft. 8 in. |
| 20° .. .. .. | 3 ft. 7½ in. |
| 25° .. .. .. | 4 ft. 8 in. |
| 30° .. .. .. | 5 ft. 9 in. |

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(iii) In certain types of aircraft the system of marking described above may be impracticable, particularly if the pilot's cockpit is some distance behind the leading edge of the main plane. In these circumstances, an alternative method of marking may be used, the fore sight being replaced by a mark on the leading edge, the drift marks being placed on the trailing edge. It will usually be necessary to lay out drift markings on both planes : port drift will then be shown on the starboard plane, and *vice versa*.

(iv) To observe the drift the pilot notes an object on the ground in line with the sights. He maintains as steady a course as possible and notes the point on the leading or trailing edge where the object appears to cut it. A disadvantage of having the drift marks on the trailing edge is that the object is out of sight and it may be found difficult to pick it up when it emerges behind the trailing edge.

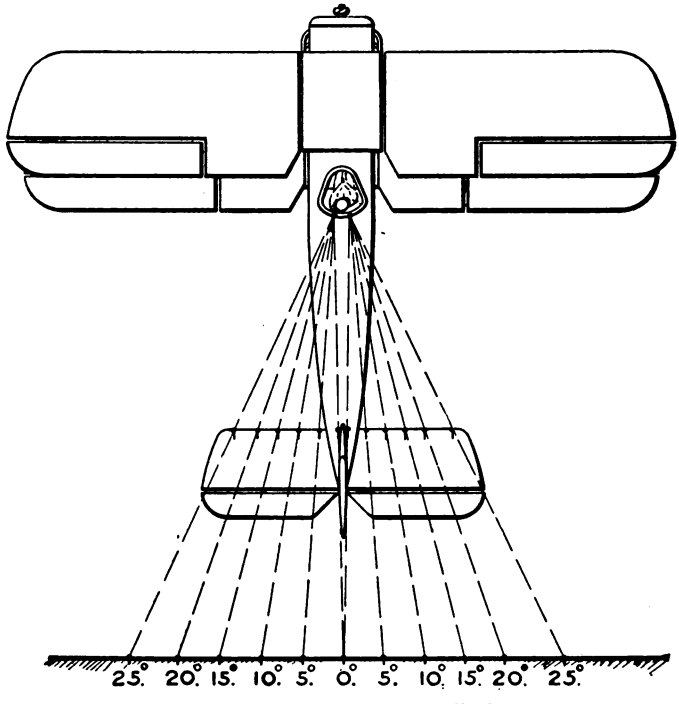


FIG. 64.—Drift markings on tail plane.

(v) Drift can also be observed by means of drift markings on the tail plane (Fig. 64). In order to lay out these markings, the aircraft should be placed in flying position with its longitudinal axis aligned on a vertical mark on the wall of a hangar.

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Vertical lines are then marked on the wall at points corresponding to angles of 5°, 10°, 15°, etc., on each side of the longitudinal axis, measured from the cockpit, and the leading edge of the tail plane is marked where these lines appear to cut it, as seen from the cockpit. This method is more suitable for two-seater aircraft, where an observer can easily see the drift markings: in a single-seater, the pilot has to turn his head to see the tail plane, and steering a steady course becomes very difficult.

### 16. The Plan Rangefinder, Mark II

The purpose of this instrument is to measure the distance of an object from the point vertically below an aircraft on which the instrument is used. The principle of the plan rangefinder, Mark II, and the methods of use are described in A.P. 1275, section 12, chapter I.

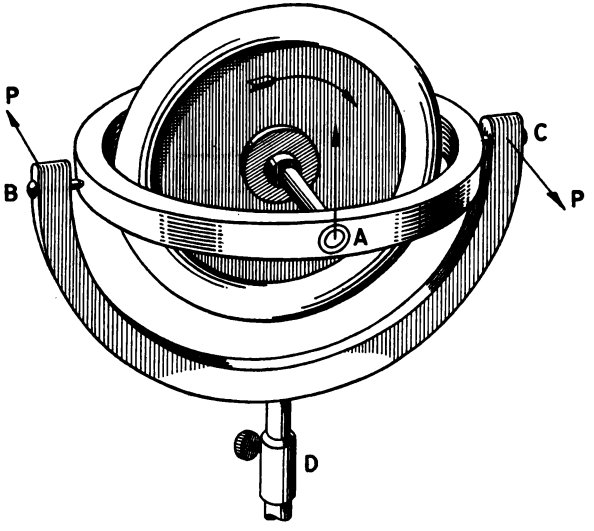


FIG. 65.—Precession of a gyroscope.

### 17. Properties of a gyroscope

(i) A gyroscope consists essentially of a rapidly spinning wheel. Such a wheel possesses, under certain conditions, the property of resisting any force tending to alter the direction of its axle. Consequently a gyroscope with its axle mounted on gimbals so that it is free to turn in any direction will maintain a given direction in space. Owing to the rotation of the earth, a freely mounted gyro will not maintain a given direction relative to the earth unless its axis is parallel to the earth's

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axis, i.e., pointing towards the Pole Star. A gyro so mounted would be an elementary form of compass. In practice, however, it is impossible to construct a perfectly balanced gyro with absolutely frictionless gimbals, so that this would not be a satisfactory type of compass.

(ii) Fig. 65 shows a gyroscope mounted so that it can spin freely about its own axis A, while it is also free to turn about the horizontal axis BC and about a vertical axis through the support D. If the wheel is spun rapidly in the direction of the arrow marked on it and a couple PP is applied tending to turn the gyro axis in the horizontal plane, the axis will not yield in this direction but instead will tilt about BC in the direction shown by the vertical arrow. Similarly, if a couple is applied to the gyro axis in the vertical plane, the axis will move in a horizontal direction. This motion is called *precession*. The direction of the precession is always such as to make the axis of rotation of the wheel move towards the axis of the applied couple, with the direction of rotation in the direction of the forces.

(iii) The properties of the gyroscope are utilised in several instruments intimately connected with air navigation, such as the automatic pilot and turn indicators.

## 18. Turn Indicators

(i) Suppose that the gyroscope described in para. 17 were mounted in an aircraft, with the clamping screw on the support D tightened. If the aircraft executed a turn, the support, and with it the vertical gimbal ring, would turn with the aircraft, and a *torque* or turning moment in the horizontal plane would therefore be applied to the gyro axis. The gyro would consequently tilt. In Fig. 65, imagine the gyro to be mounted in the aircraft with the gyro axis athwartships, C being towards the nose and B towards the tail. If the aircraft turned to the right, the resulting torque acting on the gyro axis would produce the same result as the couple shown in the figure. This is the principle of the Reid-Sigrist Turning Indicator, which is described in detail in A.P. 1275, section 1, chapter V. In this instrument the movement of the horizontal gimbal ring is controlled by a spring, so that the gyro tilts only to the point where the precessing torque is balanced by the tension of the spring. The instrument therefore indicates the *rate of turn*, a sharp turn causing a greater precessing torque than a gentle one.

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**AIR PUBLICATION 1234**
(*Revised April*, 1935)

## CHAPTER XII.—ELEMENTARY MAGNETISM

### 1. The molecular theory

(i) A great many substances have magnetic properties, e.g., iron, nickel, cobalt, and manganese. The first is vastly more magnetic than any other known substances. The magnetic properties of iron (including steel) only will be briefly considered here.

(ii) If a bar magnet be dipped into iron filings it is found that they adhere most freely at or near the ends. These places are called *poles*. On suspending the bar magnet freely and horizontally one end always points approximately northwards: the other end cannot be made to rest pointing north. Thus one pole is called the north-seeking (or " red ") pole, and the other the south-seeking (or " blue ") pole. It is universally true that red poles repel each other and blue poles repel each other, while a red and a blue pole attract each other. This may be expressed by saying that *like poles repel and unlike poles attract one another.*

(iii) The molecular theory of magnetism conveniently explains phenomena otherwise difficult to understand. The theory is that every magnetic substance (i.e., a substance capable of being magnetised) consists of smaller parts which are themselves magnets. The small parts are called molecular magnets; they are not to be confused with the chemical molecule. The minute magnets are not arranged in any one particular way when the substance is unmagnetised, but lie indiscriminately in all directions. The act of magnetisation consists in arranging them in one direction. Fig. 66 represents diagrammatically the arrangement in an unmagnetised iron bar, the arrows representing molecular magnets and arrow heads being red poles. Fig. 67 represents the same bar when magnetised.

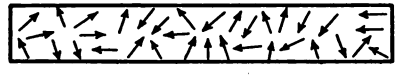

FIG. 66.—Molecular theory—unmagnetised iron bar.

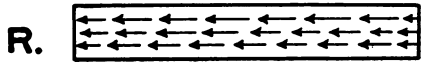


FIG. 67.—Molecular theory—magnetised iron bar.



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(iv) In Fig. 67 it is seen that at one end of the bar (R) there are free red poles without any corresponding blue poles, and at the other (B) free blue poles.

(v) Suppose the bar illustrated in Fig. 67 were broken, new poles would appear at the freshly produced ends. This is explained by the fact that the acts of breaking would leave a set of molecular blue poles to the left of the gap and of red poles to the right. A further breaking will produce additional poles, as in fig. 68. Thus, if a bar magnet be broken, each piece is found to be a complete magnet.

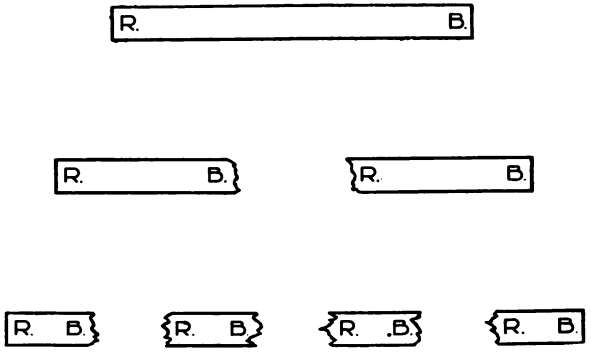


FIG. 68.—Poles of a bar magnet.

(vi) Consideration of the molecular theory leads easily to the conclusion that the poles of a magnet are inseparable, i.e., one cannot exist without the other.

(vii) The phenomenon of magnetic saturation points to the truth of the molecular theory. A magnet is said to be saturated when it cannot by any means be made more powerful. When all the molecular magnets have been turned into the same direction it is clearly impossible to increase the magnetisation. With suitable apparatus it can be demonstrated that the force exerted by the red pole of any magnet is equal and opposite to that exerted by the blue pole.

## 2. Magnetic lines of force

(i) There is a region surrounding any magnet throughout which its influence may be detected; this region is called the *magnetic field* of the magnet. The field of a powerful magnet is widely extended, but it is restricted in the case of weaker magnets. At every point in a magnetic field a magnetic pole would experience a force in some definite direction, and if the pole were free to move it would travel in that direction. It has been already stated that an isolated pole cannot be obtained, but for the purpose of this explanation let it be

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imagined that a free red pole be situated at the point R in the field of the magnet N.S. (Fig. 69). Then the red pole would experience a force of repulsion, RA, due to pole N. and a force of attraction, RB, due to pole S. The resultant of these forces (RC) would indicate the *direction of the magnetic field* at the point R, i.e., the free pole would begin to move in the direction RC. It should be noticed that the force RA is greater than RB, because the isolated pole is nearer to pole N. than to pole S. As soon as the free pole had moved, however, the forces due to N. and S. would alter becauses the distances

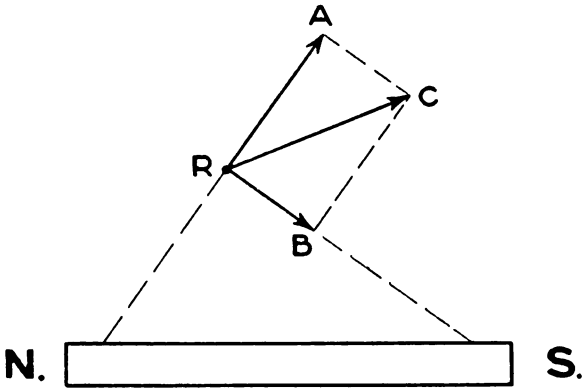


FIG. 69.—Magnetic pole in a magnetic field.

NR and SR would be different. If a number of positions of R were taken they would be found to lie in a curve running from N. to S. Such a curve indicates the direction of the *magnetic line of force*, which is a line the direction of which at each point is that of the magnetic field at that point. Alternatively, the magnetic line of force may be defined as the path along which an isolated red pole free to move would travel. The second definition leads to the useful convention that every magnetic line of force has a direction issuing from a red pole and entering into a blue pole.

(ii) Magnetic lines of force are perfectly definite lines which can never meet nor cross each other. Their directions may be crudely indicated in the following way. Place a piece of drawing paper over a bar magnet and sprinkle iron filings over the paper. Tap the paper and the filings will be seen to arrange themselves in fairly definite lines, similar to those shown in Figs. 70, 71 and 72.

### 3. The magnetic moment of a magnet

It is not convenient to compare the strengths of magnets by reference to their pole-strengths. The tendency of one magnet to turn a second magnet which is freely suspended will



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depend upon the respective lengths of the two magnets, as well as upon their pole-strengths. The measure of the tendency of a magnetic to turn, or be turned by, a second magnet is called its *magnetic moment*. The magnetic moment of a magnet is measured by the product of its pole-strength and the distance between its poles; it is a perfectly definite quantity, easily to be determined by mechanical means. It is expressed in c.g.s. units (dynes).

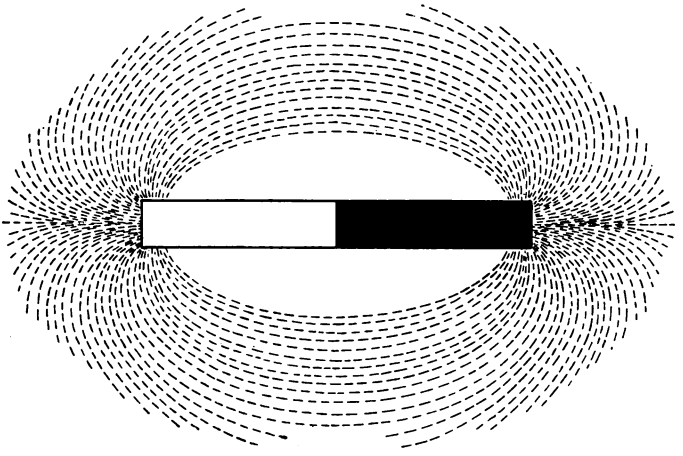

FIG. 70.—Magnetic lines of force.

## 4. The couple acting on a magnet in a magnetic field

It is important to understand clearly the forces acting upon a perfectly freely suspended magnet when it is brought under the influence of a magnetic field.

(i) Consider the magnet SN (Fig. 73) to be suspended freely in a magnetic field, the direction of which is shown by the dotted arrow. Let the pole-strength of the magnet be $m$ and the strength (or intensity) of the field be I. The magnet lies at right angles to the magnetic field. Each pole of the magnet will experience a force I$m$ dynes, as indicated by the arrows. These two forces constitute a couple and the turning moment of the couple (torque) is I$ml$ when $l$ is the distance between the poles of SN. The magnet will be impelled to turn in an anti-clockwise direction.

(ii) Consider next that instead of being at right angles to the magnetic field the magnet is inclined to the field at an angle $\theta$ as in Fig. 74. The force on each pole is still I$m$, but the perpendicular distance between the forces is now AN. AN $= l \sin \theta$ and the couple is I$ml \sin \theta$.

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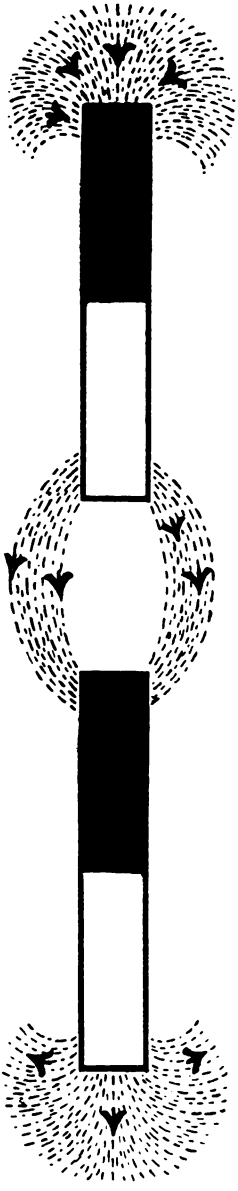

FIG. 71.—Lines of force when opposite poles of magnets are placed near each other.

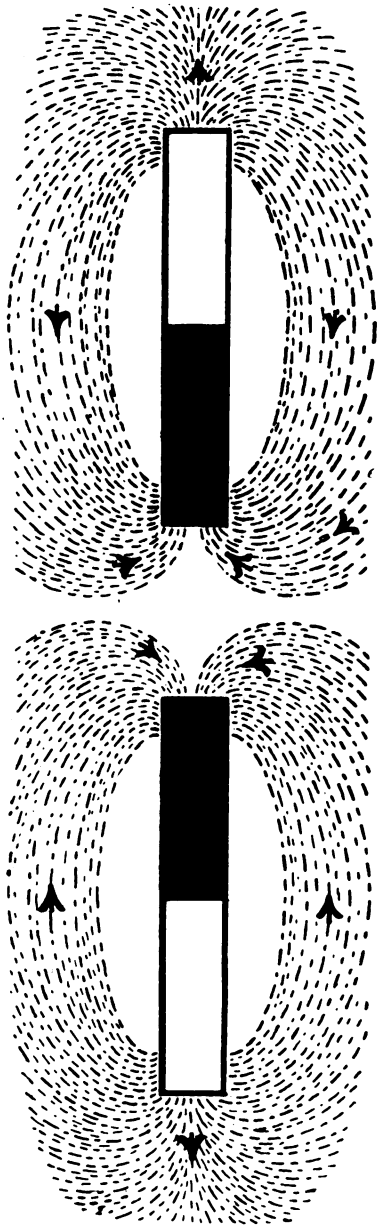

FIG. 72.—Lines of force when like poles of magnets are placed near each other.

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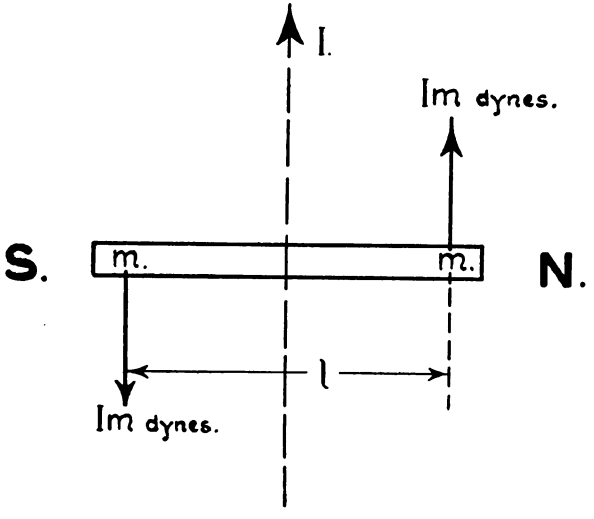


FIG. 73.—Magnetic moment of a magnet.

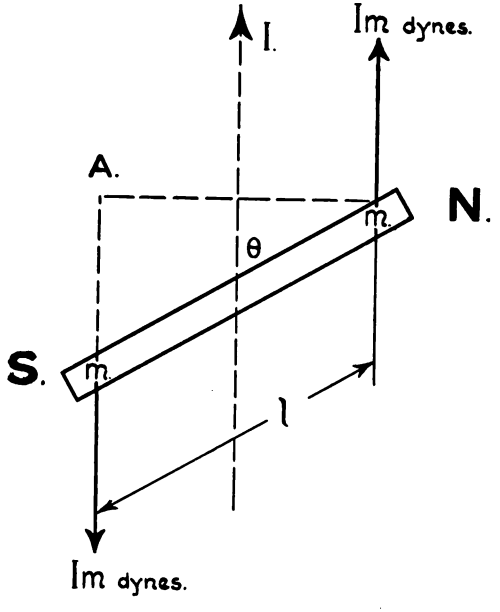


FIG. 74.—Magnetic moment of a magnet.

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Now when the angle θ becomes 0, i.e., when the magnet lies in the direction of the magnetic field, the couple becomes zero, since sin θ = 0. It follows from this that the only position in which a freely suspended magnet is in equilibrium in a magnetic field is when its axis is coincident with the direction of the field. It is owing to this fact that the magnetic compass is a practical possibility.

(iii) Suppose that a small freely suspended magnet ns were placed in the field of the bar magnet NS (Fig. 75). It would take up the various positions indicated—always coming to rest with its axis coincident with the direction of the magnetic field.

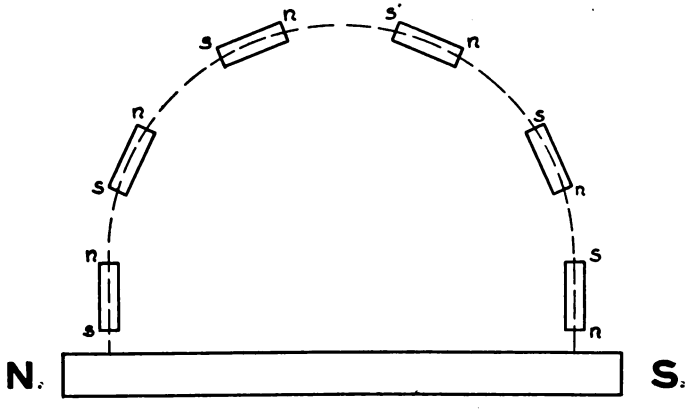


FIG. 75.—Freely suspended magnet in a magnetic field.

## 5. The magnetic field of the earth

(i) The earth is a magnet having the same characteristic properties as any other magnet. The magnetic field of the earth is subject to small changes, both irregular and periodic, which, excepting the changes in variation (*see* para. 7 below) are not of importance to an air navigator. The magnetic poles of the earth are not coincident with the geographic poles. One is situated in Baffinland (71° N., 96° W.), and the other in Victoria Land (72° S., 155° E). The magnetic poles are of considerable area. As the earth's north magnetic pole attracts the " red " pole of a suspended needle, it is itself a " blue " pole.

(ii) The needles in a magnetic compass are necessarily kept in the horizontal plane by some system of balancing. As the earth's lines of force are inclined to the horizontal, it follows that the total force of the earth's magnetism cannot be utilised in directing compass needles. The total force (I)

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of the earth's field in London is about 0·47 dyne. By the parallelogram of forces (Fig. 76) it is seen that the horizontal component is about 0·183 dynes. The horizontal force (H) is sometimes named the *directive force*. The vertical force (symbol Z) is of interest in relation to turning and acceleration

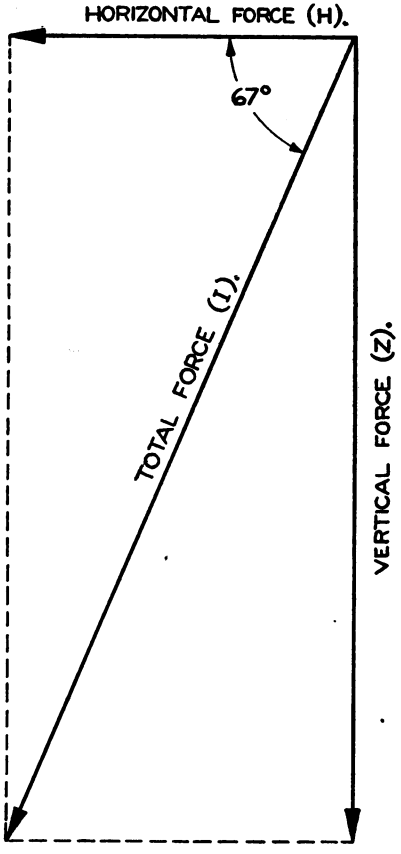


FIG. 76.—Horizontal and vertical components of the earth's magnetic field.

errors of aircraft compasses. A *dyne* (the c.g.s. unit of force) when applied to a mass of one gramme during one second will produce a velocity of one centimetre a second. It is of very especial importance to realise clearly the minuteness of the force which acts upon the magnet system of a magnetic compass.

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### 6. Magnetic dip

A magnetic needle perfectly balanced and freely suspended would point vertically downwards when brought immediately above a pole of the earth and would lie horizontally at the magnetic equator. At any intermediate position it would be tilted at some angle of depression from the horizontal. Thus, at present in England such a needle would point downwards at an angle of depression of about 67°. This is merely another way of stating that the direction of the earth's field is inclined at an angle to the horizontal, which is known as the *angle of magnetic dip*. In Fig. 77, lines are drawn which join all places where dip has the same value: these are called *isoclinals*. The *magnetic equator* may be called the line of no dip: it is a line joining all the points on the earth's surface where a magnetic needle, perfectly balanced before being magnetised, would lie in the horizontal plane.

### 7. Magnetic variation

(i) Owing to the fact that the magnetic poles of the earth are not coincident with the geographic poles, and that the earth's magnetic field is unsymmetrical, a compass needle placed at any point will not necessarily lie in the true meridian but will lie in the magnetic meridian. The angle, measured in the horizontal plane, between the magnetic and true meridians is the angle of *variation*.

(ii) The variation for any given place may be obtained from magnetic charts, but practically every map or chart used in the air contains information about the variation for the region represented on it. It will be seen from the magnetic chart illustrated in Fig. 78 that variation has widely differing values at different places. On a magnetic chart, lines are drawn joining places at which variation has the same value; these are called *isogonals*. The line of no variation is called the *agonic* line.

(iii) The value of the variation changes slowly and fairly regularly at any given place. This change can be conveniently explained by imagining that the magnetic pole describes a path about the true pole in the direction E–S–W. in the course of about 960 years. The values of variation which have been observed in London are:—

In 1580 the variation was $11\frac{1}{4}°$ E.
In 1659 ,, ,, ,, nil.
In 1823 ,, ,, ,, $24\frac{1}{2}°$ W.
In 1935 ,, ,, ,, $11\frac{1}{4}°$ W.

It has been computed that there will again be no variation at London in the year 2139.

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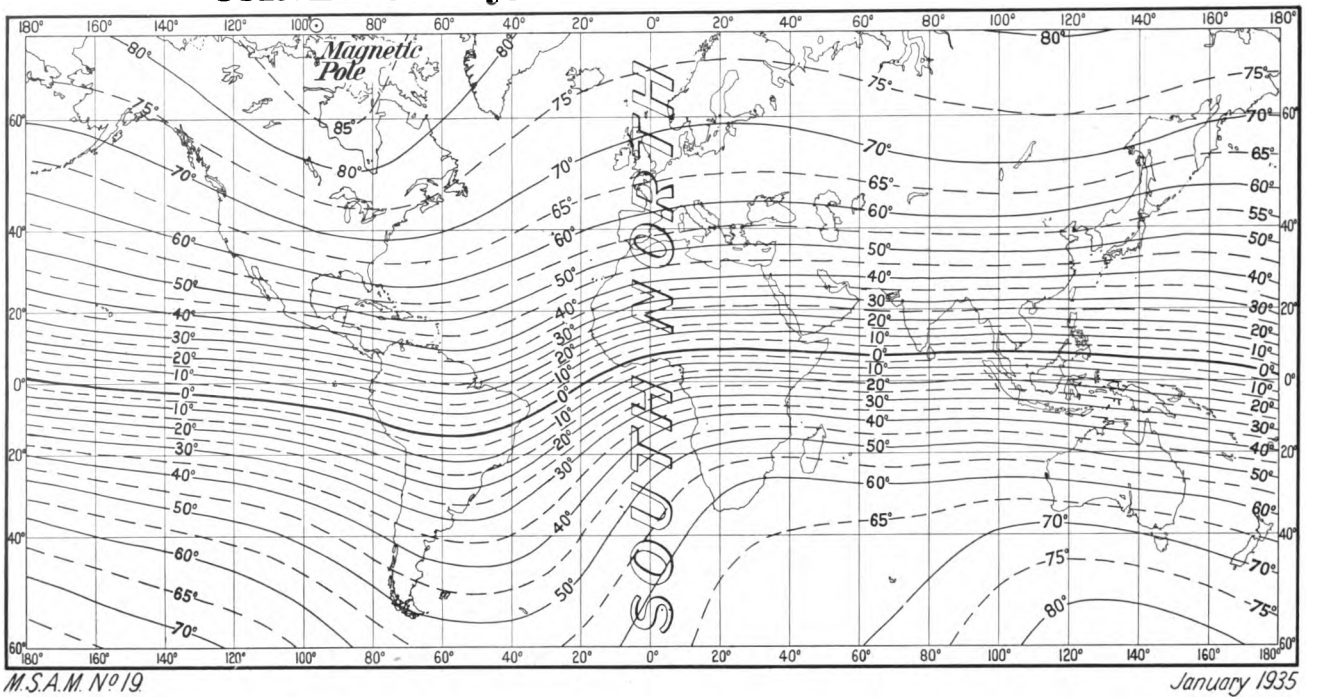


FIG. 77.—Magnetic dip chart.



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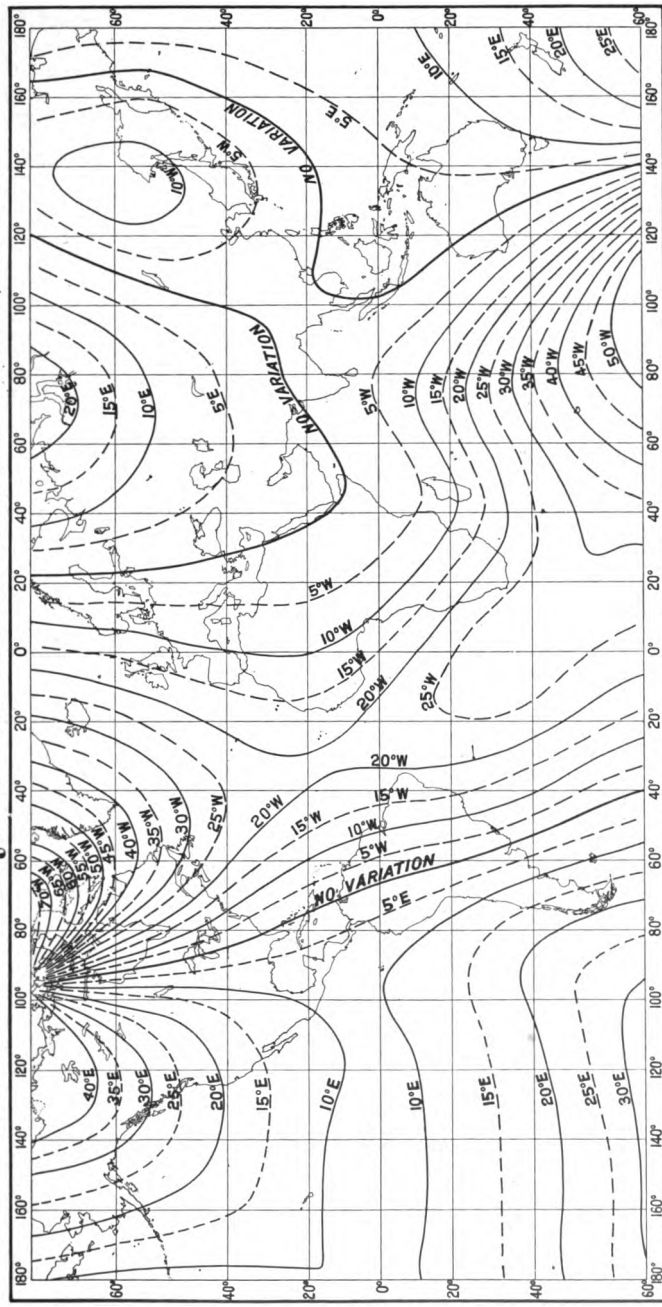


FIG. 78.—Magnetic variation chart.

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The annual change of variation is given on most maps and charts. The rate of change is not constant over the whole of an area, any more than is the value of the variation, but the differences over an area the size of England are not worth consideration. The average rate of change in England at present is about 11 minutes annually.

### 8. Hard iron and soft iron

(i) Irons and steels are sometimes termed " hard " or " soft " with reference to their magnetic properties and apart from qualities of brittleness, malleability, etc. The chief difference between hard iron and soft iron is that the latter is easily magnetised and readily demagnetised, while the former is not so easily magnetised, but retains its magnetism much longer. The two terms are both comparative ; it is impracticable to obtain an iron which is either perfectly hard or perfectly soft. The magnetism acquired by hard iron is sometimes called " permanent " and that of soft iron " temporary." These terms, also, must be regarded as comparative and not absolute.

(ii) The characteristic property of soft iron may be observed readily in the following way. Test a bar of soft iron for magnetism by dipping it into iron filings. It will not pick up any filings. Next apply a powerful bar magnet to one end of the iron bar (Fig. 79) and while the magnet is still in contact again dip the iron bar into the filings. A large quantity of filings will adhere to the iron bar, demonstrating that it has become a powerful magnet. If the polarity of the iron bar be tested it will be found that the end in contact with the N. (red) end of the magnet has become a S. pole. According to the molecular theory, magnetic lines of force have issued from the red pole of the magnet and entered

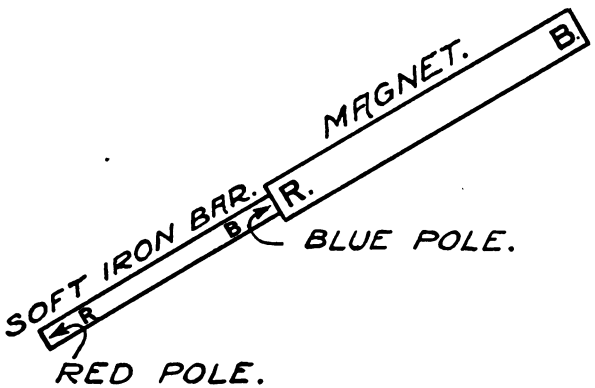


FIG. 79.—Magnetisation of soft iron bar.

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the soft iron, which provides for them an easier path than air. Following up the convention, the lines of force enter the end of the bar at B and form there a blue pole, leaving it at R which accordingly becomes a red pole. When the bar magnet is removed, the filings fall off the iron bar almost at once and so long as the bar is kept out of the field of the magnet it will not be found to possess any appreciable magnetism.

(iii) When any magnet attracts a piece of soft iron the action described above takes place ; the soft iron is magnetised while within the field of the magnet. Its magnetism, which is known as " induced " magnetism, is almost immediately lost when it is removed from the field of the magnet. The soft iron bar will be magnetised to a smaller degree if placed near, without touching, the magnet. On repeating the experiment illustrated in the diagram (Fig. 79) with a steel rod it will be found that it is not nearly so strongly magnetised by contact with the magnet as was the iron rod, but on removing the magnet the steel rod is found to retain its magnetic properties.

### 9. The inverse-square law

The force between two point poles varies inversely as the square of their distance apart. When, as is almost always the case, both poles of a magnet are acting, then the total force of the magnet varies inversely as the cube of the distance, nearly. This has some application to the correction of a magnetic compass by means of permanent magnets. Thus, if a magnet at 10 cms. from a compass needle will deflect it through 6°, at 5 cms. distance the deflection would be nearly 48°.

### 10. Magnetisation of a steel bar

(i) A steel bar may be magnetised by being placed within a magnetic field, as has already been said, but unless the field

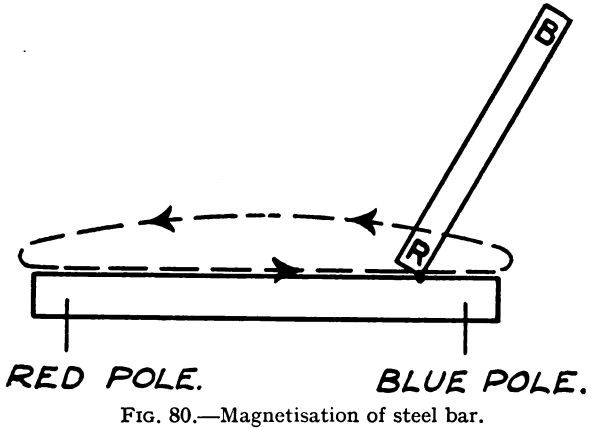


FIG. 80.—Magnetisation of steel bar.

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was a very powerful one the bar would be only feebly magnetised. A fairly powerful magnet may be made by placing the steel bar on a table and stroking it from end to end with a bar magnet, the same pole always being brought into contact with the bar. The steel would in the conditions illustrated in Fig. 80 be magnetised as shown : this would be expected from the molecular theory of magnetism.

(ii) A permanent magnet may be made by subjecting a steel bar to vibration while lying in a magnetic field. This can easily be demonstrated by placing one end of an unmagnetised bar of steel on the pole of a bar magnet and tapping the bar with a hammer. A steel bar can be made feebly magnetic by holding it tilted downwards at an angle of about 67° with the lower end pointing northwards and then tapping it. (Vibration in the earth's magnetic field.)

(iii) If a steel rod be heated bright red and allowed to cool while lying N. and S. it will be permanently, but weakly, magnetised. If it be allowed to cool within a powerful magnetic field with its axis lying in the direction of the field, the rod will be more powerfully magnetised.

(iv) Very powerful magnets are made by means of an electric current. Whenever a current flows in a conductor a magnetic field is set up. If a steel bar be placed inside a

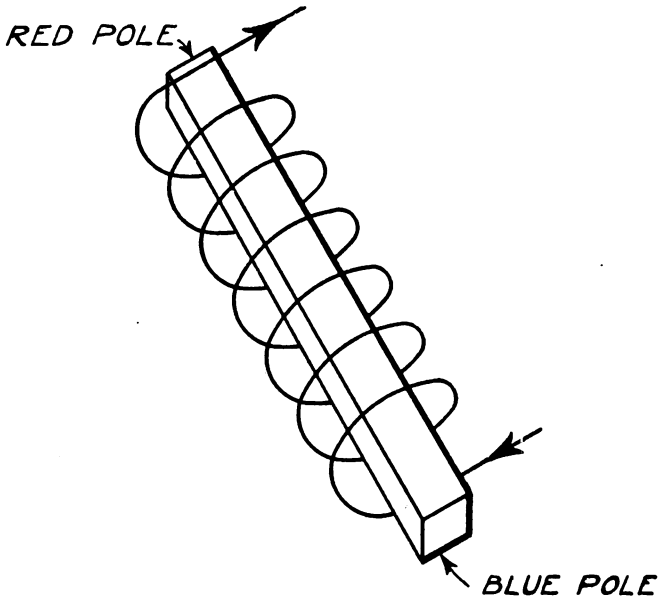


FIG. 81.—Magnetisation by electric current.

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coil through which a powerful direct current is passing, it will become a permanent magnet. With the current flowing in the direction shown in Fig. 81 the polarity of the magnet would be as indicated.

(v) Permanent magnets, however made, may be demagnetised in various ways without difficulty. If a magnet be subjected to percussion or vibration (excepting in the special circumstances mentioned above) its magnetism will be reduced. Thus, if a bar magnet be dropped upon a hard surface its magnetism will probably be diminished considerably. The application of heat tends to destroy or disturb magnetic properties. If a magnet be allowed to rust or corrode, its power will be reduced. By reversing the current in the apparatus shown in Fig. 81, the magnetisation of the bar could be reduced until a stage would be reached when the bar would cease to be magnetic.

(vi) The ambiguity of the term "permanent" as applied to hard iron magnets should now be apparent. The magnetism of a steel bar is liable to be varied—either increased or reduced—by a variety of causes of common occurrence. One can scarcely imagine any piece of steel which has not been subjected during manufacture to one or more of the processes referred to above. Actually, it is difficult to obtain ordinary steel which does not possess magnetic properties in some degree.

(vii) In order to conserve their properties, magnets must be stored in pairs with opposite poles together and must not, of course, be exposed to any of the conditions outlined here as being likely to reduce their magnetism.

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**AIR PUBLICATION 1234**
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## CHAPTER XIII.—AIRCRAFT COMPASSES

### 1. The functions of a magnetic compass

(i) The compass is a most necessary instrument for flight over unfamiliar country, over the sea, in fog, in or above clouds, and at night. It is essential for pilots and navigators to know the principle underlying the use of the compass, and to understand its limitations as well as its possibilities.

(ii) The function of a magnetic compass is to indicate the direction of the magnetic meridian, to show the course of the aircraft relative to this meridian, and also to measure bearings of distant objects. Pilot's type compasses indicate the course, and observer's type compasses are primarily intended for taking bearings through a suitable sighting arrangement, though in most of such compasses the course is indicated also.

(iii) Modern aircraft compasses are graduated every 2° from 0° to 360°, and are also marked with the eight cardinal and quadrantal points. Courses and bearings can be read to the nearest degree. A compass will continue to perform satisfactorily in a steady climb or glide, provided that the longitudinal axis of the aircraft is not inclined to the horizontal at more than 20°, but in turns or rapid changes of speed the compass does not indicate direction correctly. For reasons discussed in para. 4 of this chapter, even slight changes of course or speed may cause temporarily several degrees of deviation.

### 2. Design and construction of R.A.F. compasses

(i) A magnetic compass consists of a suitable magnet system supported on a pivot inside a compass bowl. In order to damp out oscillations of the magnet system, the compass bowl is completely filled with liquid: this has the additional effect of reducing the weight carried by the pivot. The bowl is normally cylindrical in shape, with a glass top, and is mounted in a container which is rigidly attached to the aircraft. To prevent vibrations from being communicated to the magnet system, the bowl is mounted in a sprung system. Rubber sponge is at present generally used, as it has been found to be the most suitable material. The bowl is supported in its container in such a way that some small play is allowed in the fore and aft and athwartships directions, but no turning of the bowl relative to the container is permitted. This is ensured by the use of a "*floating ring*" between the container and the bowl. In all compasses issued since 1933, except the Type O·3, a modified suspension system has been introduced.



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In this system damping springs have been fitted to prevent excessive " sloppiness " of the suspension. The lugs on the container through which the securing bolts pass are slotted in order to allow small adjustments in azimuth. Mounted above the compass bowl in such a way that it can be clamped to the bowl is the *grid ring* (in all pilot's type compasses except the P.3) or *azimuth circle* (in observer's type). A *lubber line* is fitted inside the bowl to indicate the direction of the aircraft's head. The line joining the lubber line to the centre of the compass should be exactly in, or parallel to, the longitudinal axis of the aircraft. For details of setting and reading courses and bearings *see* para. 5 below.

(ii) An undamped compass needle deflected from the magnetic meridian would carry out a large number of oscillations before coming to rest. The time in seconds to complete one oscillation is called the *periodic time* of the compass. If such a compass needle were mounted in an aircraft, it would be liable to be deflected owing to rolling and pitching of the aircraft. If the period of roll or pitch of the aircraft synchronised with the period of the compass system, the maximum effect would occur, and the needle would swing to and fro.

(iii) By suitable design and by means of damping the magnet system can be prevented from ever completing an oscillation. The characteristics of such a system are heavy damping and a large magnetic moment compared to the inertia of the system, which must be small. The damping is secured by fitting damping filaments—which are thin metal rods or glass tubes—to the magnet system. The damping filaments project into the liquid, and, by reason of the resistance offered by the liquid, exercise the damping effect. The further the filaments project, the greater is the damping produced. A large magnetic moment is necessary in order that the compass shall not be sluggish in action. The general practice is to use four or six short, powerful magnetic needles instead of the two longer needles usual in older types. A small inertia is essential. This is obtained by reducing the weight of the system as much as is practicable and by concentrating its mass as close to the centre as possible. A typical system weighs 1/10th ounce in air. It is not feasible to fit a card of anything like the usual size without increasing the inertia of the system too greatly. This has led to the adoption of such special methods of indicating the course as are embodied in the P.4 and O.3 types and which are described later.

Since a heavily damped system of the type described will never complete an oscillation after deflection, it follows that it cannot have a periodic time : it is accordingly described as *aperiodic*. The essential advantages of an aperiodic system

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are that, after being disturbed, it " gets off the mark " quickly on its journey back to the meridian by virtue of its comparatively strong magnetic moment and " pulls up " promptly on nearing its resting position by reason of its heavy damping. The magnet system is very carefully balanced, and is mounted on a suspension that is as nearly frictionless as possible. This consists of a pivot, of german silver tipped with iridium, bearing on a cup of sapphire mounted on a stem attached to the bottom of the compass bowl in such a manner that the system cannot become unshipped. Needless to say, all parts of a compass other than the magnets themselves are made of non-magnetic material. For the bowl and container brass is generally used, and magnet systems are of german silver.

(iv) The liquid used must fulfil certain requirements, of which the most obvious are transparency and cheapness. As modern aircraft operate at high altitudes, it is necessary to use a liquid which has a low freezing point and, at the same time, a small coefficient of expansion so that unduly large differences of volume of the liquid may not result from temperature changes. An alcohol solution is found to be the most satisfactory liquid.

A disadvantage of filling the compass bowl with liquid is the effect known as *liquid swirl*. When the bowl is turned, the viscosity of the liquid causes it to be dragged round with the bowl, and eddies are set up at the circumference which tend to set up rotations of the magnet system. In order to minimise swirl effect, it is necessary to leave a certain clearance between the magnet system and the bowl ; thus an efficient compass cannot be made very small. Alcohol has small viscosity and the bowl is made cylindrical to minimise the effect, but liquid swirl is stlil a noticeable cause of error during changes of course.

(v) The temperature range through which aircraft compasses are required to function is from + 50° to — 50° Centigrade. The total change in volume of the liquid between these extreme temperatures is about 12 per cent. To allow for this contraction and expansion, an *expansion chamber* is fitted below the bowl in communication with it. This may consist of a thin flexible box formed by two corrugated diaphragms of german silver, but in most modern compasses a *sylphon tube* of brass is used (*see* Fig. 82).

(vi) Alcohol has the serious disadvantage of acting on most paints, many metals, and on sulphur (which is contained in the rubber gaskets used at joints in the bowl). Thus compasses filled with alcohol tend to discolour. All aircraft compasses are coated inside the bowl with a black alcohol-resisting paint. This makes the compass easier to read, both by day and night.



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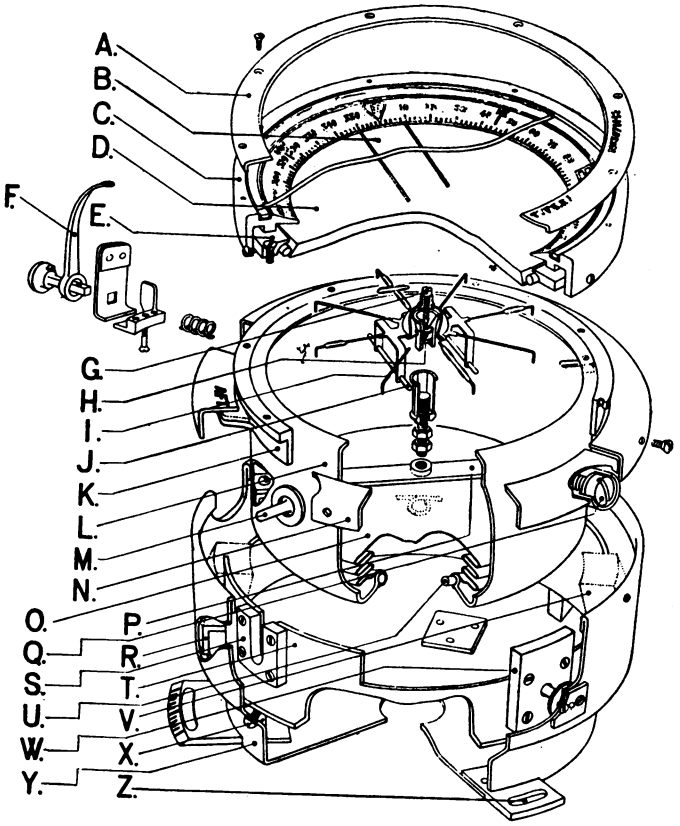


FIG. 82.—Diagram of Type P.6 compass.

A. Clamp ring.
B. Cover glass.
C. Grid ring.
D. Verge glass.
E. Verge ring.
F. Grid ring clamp.
G. Pivot.
H. Cup.
I. Damping wires.
J. Magnets and frame.
K. Bowl ring.
L. Bowl with lubber line.
M. Guide pin.
N. Lid ring.
O. Sylphon tube.
P. Bridge.
Q. Filler plug.
R. Angle bracket.
S. Guide.
T. Floating ring.
U. Gasket.
V. Sponge rubber.
W. Guide.
X. Support for floating ring.
Y. Container.
Z. Securing lug.

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(vii) The magnet systems and lubber lines of modern compasses are luminised by means of small diameter glass tubes which are filled with mesothorium compound and sealed. Mesothorium is a luminous radio-active substance, which is much cheaper than the radium compounds previously used.

(viii) The following distinguishing marks are used on compasses :—

P before the type number indicates Pilot's Compass.
O before the type number indicates Observer's Compass.

The design of all P. and O. type compasses originates from the Admiralty Compass Observatory, but the compasses are constructed by contractors. The manufacturers are indicated by a letter following the serial number, thus :—

H—Messrs. Henry Hughes & Sons, Ltd.
D—Messrs. Dent & Co. and Johnston Ltd.
K—Messrs. Kelvin, Bottomley & Baird.
W—Messrs. E. R. Watts & Son, Ltd.

S after the serial number indicates that the modified suspension system referred to in sub-para. (i) above is fitted.

Some compasses will also be found to be marked with a * and/or an M. These symbols indicate processes that are now standardised, and the symbols are therefore obsolescent.

* indicated that the liquid had been de-aerated.

M indicated that mesothorium compound was used as the illuminant.

### 3. The correction of dip

(i) The magnetic compass obtains its directional properties from the earth's magnetic field. The direction of this field is inclined to the horizontal at the angle of dip, and a magnetic compass needle, supported at its centre of gravity, will therefore take up the angle of dip. In a compass, however, it is necessary that the magnet system shall be horizontal or as nearly horizontal as possible. The method of overcoming dip adopted in aircraft compasses is to make the magnet system pendulous by supporting it at a point above the centre of gravity.

(ii) Fig. 83 shows in diagrammatic form a magnet system supported on a pivot at the point P a short distance above the centre of gravity G. (In aircraft compasses, the distance PG is of the order of 1/20th inch.) For simplicity, the magnet system is shown as containing only one magnet, though in practice there are always two, four, or six magnets. Also, the centre of gravity is shown as being at the centre of the magnet, though in an actual magnet system its position would be slightly nearer the pivot.

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In Fig. 83 the compass is assumed to be at the magnetic equator, where the angle of dip is zero. The magnet system will, therefore, lie in the horizontal plane, and its weight (W), acting through the centre of gravity, will be in the same straight line as the equal and opposite reaction (R) acting through the pivot. The magnet system is maintained in the magnetic meridian by the horizontal component H of the earth's total force.

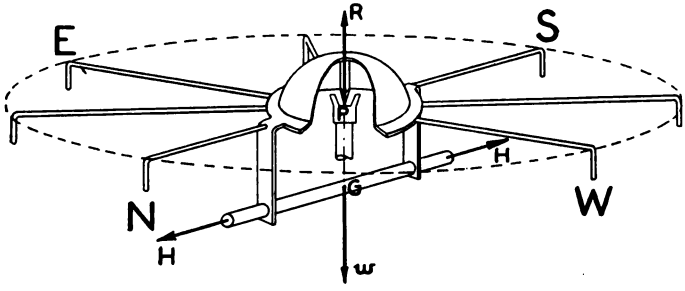


FIG. 83.—Magnet system at the magnetic equator.

(iii) Fig. 84 shows the effect of the vertical component Z of the earth's total force (in the northern hemisphere). This applies a couple to the magnet system, tilting it in the vertical plane through NS, so that G is no longer vertically below P. This displacement of the centre of gravity results in a couple which opposes the couple due to Z, the forces composing the couple being the weight (W) acting through G and the equal and opposite direction (R) acting through P. There is also a small righting couple due to H. A position of equilibrium is reached when these couples balance the couple due to Z.

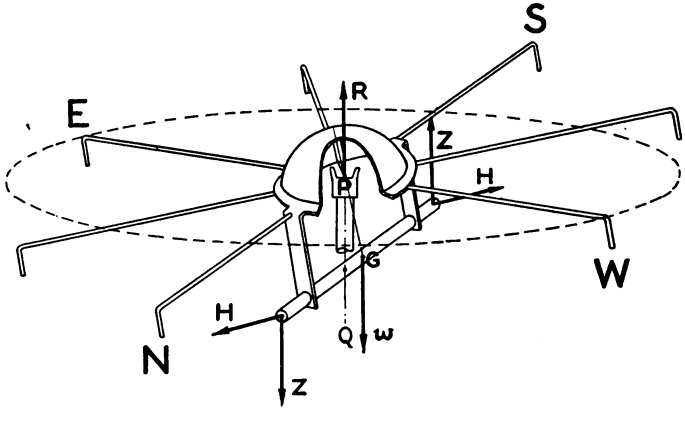


FIG. 84.—Effect of dip on the magnet system.

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Thus, except at the magnetic equator, the magnet system of an aircraft compass will never lie exactly in the horizontal plane, and the amount of tilt will increase as the value of Z increases. The centre of gravity will always, except at the magnetic equator, be displaced to the north or south of the vertical line through the pivot, as indicated by PQ in Fig. 84. This displacement is to the south in north magnetic latitudes and to the north in south magnetic latitudes. In practice the amount of tilt will never exceed 3°, which is insufficient to cause appreciable errors of parallax when using the compass.

It was at one time customary to make the magnet system lie exactly horizontally in these latitudes by shifting the magnets in their holders slightly towards the south thus moving the centre of gravity to the south of the centre of the system, but this practice is now discontinued, in order to avoid the increased tilt involved when compasses are taken to south latitudes.

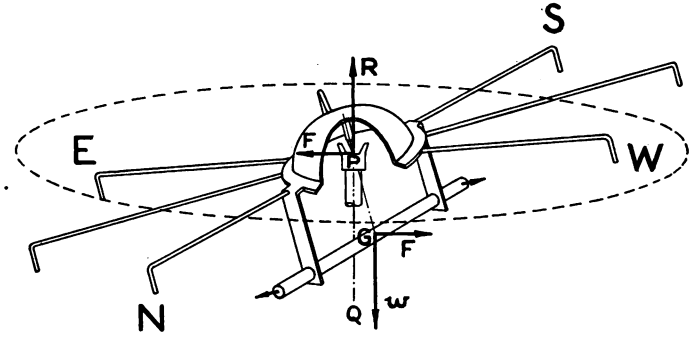


FIG. 85.—Turning and acceleration errors.

## 4. Turning and acceleration errors

(i) When an aircraft executes a turn, a *centripetal force*, the value of which depends on the speed of the aircraft and the radius of the turn, acts through the pivot of the magnet system along the line from the compass to the centre of the turn. An equal and opposite reaction, commonly called *centrifugal force*, acts at the centre of gravity. Suppose that an aircraft flying on a northerly course in the northern hemisphere begins a turn to the right, i.e., to the east. Then a force F acts in a westerly direction through G, and it will be seen from a consideration of Fig. 85 that this will cause—

(*a*) a clockwise rotation of the magnet system giving easterly deviation, owing to the fact that G is to the south of the pivot, and

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(*b*) a tilt of the magnet system caused by a displacement of G towards the west. When this tilt occurs, the earth's total force has a component in the plane of the magnet system at right angles to the magnets which causes a further clockwise rotation and so increases the easterly deviation.

By similar reasoning it will be seen that turns from north towards west cause westerly deviation.

(ii) The effect of turning from a northerly course is to cause the magnet system to turn in the same direction as the aircraft. There are three possible results, depending on the rate of turn :—

(*a*) If the magnet system turns more slowly than the aircraft, a turn in the correct sense will be registered, but smaller than that actually made.

(*b*) If the rates of turning of the magnet system and the aircraft are equal, no change of course will be indicated.

(*c*) If the magnet system turns more quickly than the aircraft, a turn in the wrong direction will be indicated. This will normally only occur in a very steep turn. This is technically known as *northerly turning error*.

(iii) Consider the effect of a turn from south to west. It will be seen that westerly deviation results. Similarly, in turning from south to east, easterly deviation results. Hence, in turns from a southerly course, the magnet system and the aircraft are turning in opposite directions, and the compass will register a turn in the correct sense but greater than that actually made.

(iv) Since the centripetal force and consequently the deviation of the magnet system depend only on the rate of turn, the amount of turning error should be the same whether the turn is flat or banked. In practice, however, the rate of turn is generally less in a flat turn than in a banked turn and therefore the resulting deviation is smaller. Also, in a flat turn, the damping action of the liquid tends to reduce the amount of tilt of the magnet system, whereas in a banked turn the compass bowl tilts with the magnet system.

(v) When an aircraft turns, deviation of the compass is caused by liquid swirl (*see* para. 2 (iv) above). For example, in turning from north to east, the compass is rotated clockwise and the liquid in the bowl tends to turn with the bowl and to drag the magnet system round with it. Thus an easterly deviation is caused. In turning from south to east, the rotation is anti-clockwise, and a westerly deviation results.

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Hence liquid swirl tends to increase the deviation of the compass in turns from northerly courses, and to decrease the deviation in turns from southerly courses.

For small alterations of course the effect of liquid swirl is negligible, but in sustained turns the effect is appreciable and may persist for some time after the turn has been completed.

(vi) Suppose that an aircraft flying on an easterly course in the northern hemisphere increases speed. In order to cause a body to accelerate, a force must be applied to it in the direction of motion. Thus a force F in an easterly direction is applied to the magnet system at the pivot P, which is its sole point of attachment to the aircraft (*see* Fig. 85). Owing to its inertia, the magnet system tends to lag behind. Hence a force due to the inertia, equal and opposite to that applied to the pivot, will act through the centre of gravity G. As in sub-para. (i), a clockwise rotation of the magnet system, i.e., an easterly deviation, results.

Acceleration on a westerly course causes westerly deviation, while decelerations cause deviations in the opposite directions.

(vii) In southern magnetic latitudes the effects described as occurring on northerly courses occur on southerly courses, and vice versa. Acceleration errors are in the opposite directions to those described.

(vii) Although turning error has only been considered with reference to turns from northerly and southerly courses, and acceleration error with reference to easterly and westerly courses, these errors also occur on other courses, though turning error is at its maximum on a course of due north and acceleration error has its maximum effect on due east and due west and is zero on due north and due south.

In banked turns, even with an angle of bank of only 10°, large deviations may occur, and a compass will not therefore indicate direction correctly during a turn, nor for a short period after the turn has been completed. Turning and acceleration errors may have effect even in quite small changes of course and speed due to slight rolling, yawing, or fore and aft pitching such as may be almost unnoticeable to the pilot. Investigation has shown that under certain conditions temporary deviations of from 1° to 5° may occur, although the aircraft is apparently steered on a steady course. A single observation of course or bearing made at one given instant should therefore be used with caution, though over a period of time the average reading will be correct. Pilots should make themselves familiar with the behaviour of their compasses by observing their performance during flight. The time necessary for the compass to settle down after a turn should be noted.

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**5. Types of compasses in use in the Royal Air Force**

Types of compasses in use are described and illustrated in section 8 of A.P. 1275, General Instrument Equipment for Aircraft, Vol. I. The principal features are as follows :—

(i) *Type P.3 compass.*—This compass has a vertical card and a spherical bowl, with the glass window at the rear, so that it can be mounted in the pilot's normal line of vision. The course is read from a lubber line registering against the after side of the compass card. The disadvantages of this type are that the card, owing to its small size, is only graduated to 5°, and parallax errors are appreciable unless the course is read from immediately aft of the lubber line. Also, since the lubber line is aft of the compass, the markings on the card are reversed, and it is difficult to obtain a general idea of the direction of the points of the compass.

The P.3 compass is obsolescent.

(ii) *Type P.4 compass* (Fig. 86).—This is a grid steering compass and is the standard pilot's compass in the Royal Air Force.

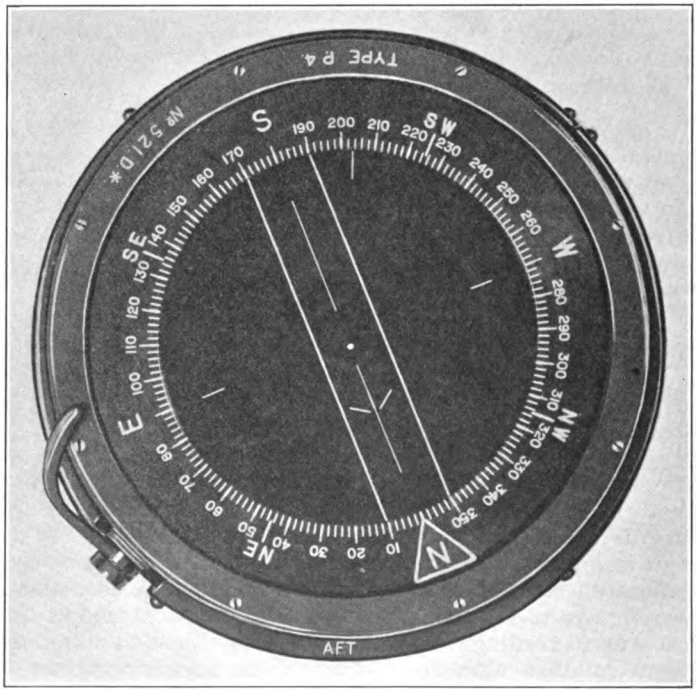


FIG. 86.—Type P.4 compass.

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A rotating grid ring is fitted above the bowl and can be locked in any position by means of a locking arm on the left side of the bowl. Two parallel grid wires are placed across the grid ring and the inner edge of the grid ring is graduated every 2°.

*To read the course of the aircraft.*—Turn the grid ring until the grid wires are parallel to the N and S wires of the magnet system and " N " on the ring registers with the " N " wire. Read the course as indicated by the lubber line against the grid ring.

*To set a course.*—Turn the grid ring until the desired course is registered against the lubber line. Then turn the aircraft until the grid wires are parallel to the N and S wires and the " N " wire registers with " N " on the grid ring.

If the plane of the magnet system is not parallel to the plane of the grid wires, an error of parallax will occur on the quadrantal points, unless the observer's eye is immediately over the centre of the compass. When the aircraft is in flying position, the error is negligible.

Since the lubber line is appreciably below the graduations on the grid ring, an error of parallax may also occur in reading a course. The eye should therefore be as nearly as possible in the vertical plane through the lubber line and the centre of the compass.

The advantages of this type of compass are :—

(*a*) The design permits the compass to be mounted in positions other than directly in front of the pilot without the effect of parallax becoming serious when a given course is steered.

(*b*) An accurate course can be set and can be steered without the necessity of concentrating on a small lubber line registering on a scale.

(*c*) Steering a course at night is facilitated.

(iii) *Type P.6 compass.*—In all essential details this compass is similar to the P.4 but its diameter is 2 inches smaller and its weight is less than half that of the P.4. The magnet system has only 2 magnets while the P.4 has 4.

(iv) *Type P.7 compass.*—This compass consists essentially of a P.6 compass fitted with a glass bottom. The grid ring is mounted on the top of the compass bowl, and below the compass is an adjustable mirror which reflects the magnet system and grid wires. This compass has the advantages of the grid steering type and also the additional advantages that it is mounted in the pilot's line of vision and that there is no error due to parallax when either setting or steering a course.

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(v) *Type* O.2 *compass.*—This is an observer's type compass. The design of the bowl and suspension is similar to that of the P.4, but the grid ring is replaced by a rotating azimuth circle carrying a prism and sighting device. A small compass card is mounted on the magnet system, the figures on which are reversed since they are to be read through the prism. The course is determined by means of a lubber line registering directly against the card.

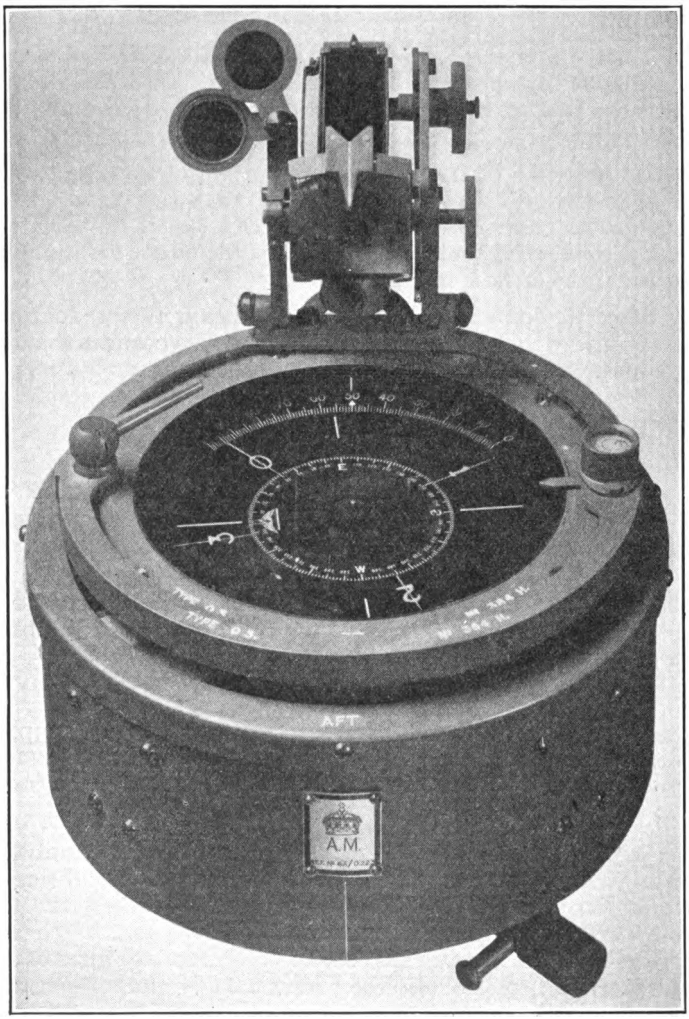


FIG. 87.—Type O.3 compass.

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(vi) *Type* O.3 *Compass* (Fig. 87).—This compass is similar to the O.2, but the course is read by means of a centesimal scale. The magnet system carries, in addition to the compass card, four luminised damping filaments, pointing to N., E., S. and W. Four additional damping filaments, numbered 0, 1, 2 and 3, register against a centesimal scale placed forward in the bowl. Suppose the damping filament numbered 2 were opposite 74° on the scale, then the course would be 274°.

To take a bearing by O.2 or O.3 compass, set the sights on the object, and adjust the prism until the reflection of the scale can be seen. Read the bearing on the scale opposite the centre line of the prism. A mirror and colour shades are provided in order to enable bearings to be taken of the sum.

(vii) *Type* O.4 *compass.*—This is a hand bearing compass. When taking a bearing, hold the compass so that the bowl is horizontal and train the fixed sighting device on the object: the bearing is read from the card through the prism. Care must be taken that the compass is as far as possible from magnetic material when being used for taking bearings. The bowl has a glass bottom and can be illuminated at night by a small electric battery and bulb contained in the wooden handle.

(viii) *Landing compasses.*—There are two types, " small " and " medium ". These are small portable liquid-filled compasses with a card and sighting device, supplied with a tripod for use on the ground for compass adjustment, etc. Bearings are read through a magnifying prism from the after end of the card, and therefore the markings on the card are reversed.

## 6. Corrector devices

In order to correct deviation in a compass, it is necessary to be able to apply small magnetic fields fore and aft and athwartships near the compass. Corrector devices are used for this purpose, and are mounted underneath the compass. There are two types of corrector device :—

(i) *Corrector magnets.*—Corrector magnets are placed in suitable containers, of which there are two types. For P. type compasses, a readily detachable wooden box is mounted as a separate unit immediately below the compass. For O. type compasses, the corrector box takes the form of a brass standard containing small tubes in which corrector magnets can be inserted. The standard forms the mounting for the compass, and its base plate has three slots for the securing bolts and permits of small adjustments in azimuth.

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Corrector magnets are available in four thicknesses :— $\frac{3}{32}$ in., $\frac{1}{16}$ in., $\frac{1}{32}$ in. and $\frac{1}{50}$ in. The standard length is 2 in., but $1\frac{1}{2}$-in. magnets are supplied for P.3 compasses. The P.3 and P.7 compasses have small wooden corrector boxes which form part of the compass.

(ii) *Adjustable correctors.*—The device consists of a light alloy cylindrical casing which contains two correctors, one for the fore and aft component and one for the athwartships component. Each corrector consists of a pair of magnets lying one above the other with the north-seeking pole of one magnet over the south-seeking pole of the other. When the magnets are in this neutral position, no external field is created, but by opening the poles from one another a magnetic field is produced. The magnets are operated by a key which fits into operating heads in the container. There are four of these heads ; either of the fore and aft heads, which actuate the athwartships magnets, provides adjustment for coefficient B, and either of the athwartships heads, which actuates the fore and aft magnets, for coefficient C. An index mark on each operating head shows the position of the internal corrector magnets ; when this mark is at 12 o'clock the external magnetic field is zero.

The adjustable corrector is supplied in two forms : Corrector No. 1 (Stores Ref. 6A/0364) for P. type compasses, and Standard Type O.5 (Stores Ref. 6A/0366) for O. type compasses.

### 7. Care and maintenance

(i) It is important to remember that a compass is a delicate instrument which cannot be expected to function properly unless carefully treated. A compass may become unserviceable, and every pilot should know what defects may develop and how to recognise them.

(ii) In order that a compass may remain efficient, the following rules must be observed :—

(*a*) Compasses must always be handled carefully : even slight shocks may cause considerable damage.

(*b*) O. type compasses must be kept in their boxes or stowage positions when not in use, and must not be left on their standards.

(*c*) Force must never be used to move a grid ring or azimuth circle that does not rotate freely.

(*d*) Compasses must always be stored upright, so that the magnet system is free to revolve.

(*e*) They should never be stored near electrical apparatus nor where they would be within a powerful magnetic field.

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(*f*) All compasses in store should be examined periodically by a qualified officer to ensure that they are maintained in a serviceable condition.

Full particulars of the storage and packing of compasses are given in Leaflet G.3 of A.P. 830, Vol. II.

**8. Serviceability of compasses**

Compasses may become unserviceable for several reasons, which are discussed below :—

(i) *Pivot friction.*—This is a fairly common defect in aircraft compasses, and makes the compass extremely sluggish. In extreme cases the magnet system may stick at some particular point and render the compass temporarily useless. To test for pivot friction, place the aircraft approximately in flying position and note the reading of the compass. Place a corrector magnet near the bowl at right angles to the needles, deflecting the magnet system through about five or ten degrees, then remove the magnet and wait until the magnet system comes to rest. If it settles down exactly in its original position, the compass is free from pivot friction. It is permissible to assist the compass to settle by tapping the bowl with the finger, as there is very often a small amount of pivot friction that does not seriously affect the efficiency of the compass. If the magnet system does not settle down within 1° of its original position, and the amount of friction error is more than can be eliminated by tapping, which corresponds to the vibrations of the aircraft in flight, the compass should be considered unserviceable, and should be returned to the Admiralty Compass Observatory for reconditioning.

(ii) *Discolouration.*—Few compasses remain free from this defect indefinitely. It is due to a variety of causes, for example to the alcohol in the bowl attacking the rubber sealing gaskets. A sediment often occurs, which settles at the bottom of the bowl, but when disturbed by vibrations, rises and remains in suspension while the disturbance lasts. Discolouration makes the compass difficult to read, and the compass must be considered unserviceable if, under the conditions of lighting which normally apply during flight, the course cannot be read distinctly. A discoloured compass should be carefully watched for pivot friction, as sediment may find its way into the cup.

(iii) *Excessive vibration.*—If the rubber sponge pads supporting the compass bowl are deteriorated or settled down, the vibration of the aircraft will be transmitted to the bowl and so to the magnet system, causing irregular

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movement of the system and hence an apparently unstable compass. To test, move the compass bowl lightly in the fore and aft and athwartships directions, and see that it does not come in contact with the container. If the anti-vibrational devices are in any way defective, the compass should be returned to the Admiralty Compass Observatory for repair.

(iv) *Damaged or stiff movable parts.*—The prism and sighting devices of a bearing compass are particularly liable to injury, as bearing compasses are generally mounted in exposed positions. The condition of the movable parts of a compass should be obvious upon examination. If grid rings and azimuth circles do not move freely, the force necessary to turn them may damage the anti-vibrational devices, and they should therefore be removed, cleaned and slightly lubricated with a small quantity of vaseline.

(v) *Bubbles in the compass liquid.*

(*a*) The presence of a bubble greatly accentuates " liquid swirl ", and this may cause the magnet system to swing and make it impossible for an accurate course to be steered. The formation of bubbles may be due to any of the following causes :—

(1) Leaking at places where joints have been made, e.g., filling plug, verge ring, expansion chamber, etc.

(2) Expansion chambers which are too small or too stiff to cover the temperature range experienced.

(3) The presence of air in solution in the liquid. At high altitudes the pressure on the liquid is less, and some of the air will be liberated and will form a bubble.

(*b*) In modern aircraft compasses, the liquid is adequately de-aerated before the compass is finally sealed up, and expansion chambers are designed to cover a large temperature range. Therefore, if a bubble occurs, the compass is defective and should, in the British Isles, be returned as unserviceable to the Admiralty Compass Observatory. Abroad, de-aeration plants have been supplied to certain stations, and a compass with bubble trouble should be sent to the nearest station with a de-aeration plant.

(*c*) Bubbles may be removed from landing compasses and compasses supplied for use in marine craft. Compass spirit for the purpose is supplied by the Admiralty Compass Observatory. This spirit must be diluted

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with distilled water as, owing to technical differences in construction, different types of compasses are filled with liquid of different specific gravities.

| *Type of compass.* | *Specific gravity.* | *Dilution of compass spirit.* |
|---|---|---|
| Bombsight D, P. types and O. types (except O.4) .. | 0·81 | As supplied. |
| Bombsight C and O.4 .. | 0·83 | One part of pure distilled water to ten parts of spirit measured by volume. |
| Landing and marine craft | 0·96 | Two parts of distilled water to one part of spirit, measured by volume. |

**9. Installation of compasses in aircraft**

The position of a compass in an aircraft is chosen during the construction of the first aircraft of a new type. The desiderata are satisfactory magnetic conditions, ease of reading and accessibility. It is very unlikely that an officer in a R.A.F. unit will be required to decide upon a new position. It is, however, necessary periodically to replace a compass by a new one, and it may occasionally happen that compass mountings may have to be modified if aircraft are ordered to be re-equipped with compasses of a different type. The following points should therefore be noted :—

(i) Non-magnetic metal should be used in a compass support or platform. Brass screws or bolts should be used to secure the instrument to its platform.

(ii) No part of the aircraft must come into contact with the bowl of the compass.

(iii) A compass must be attached rigidly to the aircraft in such a way that the instrument is truly horizontal (or vertical, according to type) when the craft is in normal flying attitude.

(iv) It must be mounted so that the vertical plane through the lubber line and the centre of the instrument lies coincident with, or truly parallel to, the vertical plane of the aircraft's fore and aft axis, with the lubber line forward. (In modern compasses the fore and aft line of the instrument is indicated by white lines painted on the container. Holding-down lugs are provided with curved slots to allow for correction of alignment by turning the compass in the horizontal plane.)



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(v) Some compasses carry the word " AFT " painted on one side of the bowl ; regard should be paid to this.

(vi) The corrector box or adjustable corrector device must be placed with its centre immediately below the centre of the compass. The magnet holes or operating heads must lie exactly fore and aft and athwartships respectively. The fore and aft line of a corrector box is indicated by a painted line.

(vii) Before an adjustable corrector is fitted in an aircraft, it should be tested in order to ensure that no external magnetic field exists. This can be done by placing the corrector on the top of a compass, and adjusting the operating heads until there is no deflection of the compass needle. This operation should be repeated with both pairs of operating heads in turn at right angles to the compass needle.

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## CHAPTER XIV.—THE ANALYSIS OF DEVIATION

### 1. Magnetism in aircraft

(i) Modern aircraft contain large quantities of metal capable of becoming magnetised. The "*hard iron*" parts of the structure of an aircraft may be magnetised during the process of manufacture. Such hard iron magnetism is unlikely to change considerably under normal conditions of service, and is, therefore, usually called "permanent" magnetism.

Besides the magnetism that may exist in the structure of the aircraft itself, powerful magnetic fields may be set up by such items of equipment as magnetos, generators, bombs, machine guns, telephone receivers, etc. Petrol tanks and moving parts such as control columns and rudder bars are generally of non-magnetic material, but in some older types of aircraft they are magnetic. It is quite possible that a control column, if magnetic, may deflect the magnet system of a compass several degrees when placed in the forward position. The magnetic field of a machine gun can be altered appreciably by firing a few rounds. Electrical appliances such as electrical engine speed indicators, W/T apparatus, etc., can set up magnetic fields. Electrical currents flowing in conductors near the compass may cause considerable deflection, though wires carrying currents are usually arranged in twisted pairs, which arrangement sets up no magnetic field.

(ii) The "*soft iron*" parts of the aircraft may be magnetised by induction from the earth's magnetic field. Such magnetism changes its direction relative to the longitudinal axis of the aircraft when the aircraft's course is altered.

(iii) The necessity for the structure of an aircraft, its engine and much of its equipment to consist in part of magnetic material, renders an aeroplane a peculiarly unfavourable situation for the mounting of a magnetic compass. Full consideration of the various difficulties is given in the designing and equipping of aircraft, and the compass position is always chosen where the magnetic conditions are most satisfactory. Electrical and other equipment setting up strong magnetic fields is placed at a distance from the compass, but it is not possible to find a position for a compass in a cockpit where no magnetic field, other than that of the earth, can affect it.



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(iv) Thus deviation in aircraft compasses is caused by a combination of different magnetic fields due to individual magnetic parts and items of equipment. For purposes of analysis it is separated into two types :—

(*a*) deviation due to hard iron magnetism, and
(*b*) deviation due to soft iron magnetism.

**2. Hard iron effects**

The various component magnetic fields due to hard iron magnetism combine to form a single resultant magnetic force acting on the compass in a direction which is fixed relative to the aircraft. This resultant force can be resolved into three components :—

(*a*) Fore and aft.
(*b*) Athwartships.
(*c*) Vertical.

These three components are designated by the letters P, Q and R respectively and are given the sign plus or minus according to the direction of the magnetic force. Thus + P represents a force attracting the N-seeking end of the compass towards the nose of the aircraft, + Q a force attracting the N-seeking end of the compass to the starboard side of the aircraft, and + R a force attracting it vertically downwards.

The deviation due to P is maximum when the aircraft is headed East or West and decreases to zero when the aircraft is headed North or South, where its effect is to cause an increase or decrease of the directive force.

The deviation due to Q is maximum when the aircraft is headed North or South and decreases to zero when the aircraft is headed East or West, where its effect is to cause an increase or decrease of directive force. Both P and Q have about 0·7 of their maximum effect when the aircraft is headed on any of the quadrantal points.

Since R acts at right angles to the plane of the magnet system, there is no effect on the compass in straight and level flight or in correctly banked turns.

**3. Soft iron effects**

The soft iron in an aircraft is magnetised by induction from the earth's magnetic field. This magnetism can be resolved into horizontal and vertical components whose effect on the compass may be considered as equivalent to a number of soft iron rods which become temporarily magnetised by induction from the horizontal and vertical components of the earth's field. The magnetism of a horizontal rod depends on the heading of the aircraft, being maximum when the rod is lying

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North and South and zero when it is lying East and West. The magnetism of the vertical rods is independent of the heading of the aircraft and depends only on the value of the vertical force Z.

The effect on the compass will depend on the arrangement of these rods, but since the effect of soft iron magnetism is usually small in aircraft, it is not necessary to consider the components in detail. It is, however, important to note the types of deviation that may be produced in level flight. These are as follows :—

(i) *Horizontal rods* :—

(*a*) Deviation which is the same on all headings.

(*b*) Deviation which is quadrantal in form, being maximum on the quadrantal points and zero on the cardinal points.

(*c*) Deviation which is also quadrantal, but with the maxima on the cardinal points and no deviation on the quadrantal points.

(ii) *Vertical rods* :—

(*a*) Deviation exactly similar to that produced by the hard iron component P, i.e., maximum on East and West and zero on North and South.

(*b*) Deviation exactly similar to that produced by the hard iron component Q, i.e., maximum on North and South and zero on East and West.

**4. The coefficients**

(i) The various hard and soft iron components can be grouped according to the types of deviation which they cause. These groups are five in number and the maximum angular values of the deviation produced are called the *approximate coefficients*, distinguished by the five capital letters A to E. It is necessary to know how to calculate the first three coefficients and how to correct them ; the remaining two are usually negligible in aircraft, and no provision is made in aircraft compasses for correcting them.

The necessary rules for calculating coefficients A, B and C are given below, the calculations being based on the following deviation table :—

| *Magnetic.* | *Compass.* | *Deviation.* |
|---|---|---|
| N. (000°) | 353° | + 7° (E.) |
| N.E. (045°) | 041° | + 4° (E.) |
| E. (090°) | 092° | − 2° (W.) |
| S.E. (135°) | 140° | − 5° (W.) |
| S. (180°) | 183° | − 3° (W.) |
| S.W. (225°) | 224° | + 1° (E.) |
| W. (270°) | 265° | + 5° (E.) |
| N.W. (315°) | 306° | + 9° (E.) |

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(ii) Coefficient A is caused by a combination of certain horizontal soft iron components, and its effect is a deviation which is the same on all courses. A similar constant deviation would be set up by :—

(*a*) the incorrect mounting of the compass (lubber line slewed out of its correct position) ; or

(*b*) the incorrect mounting of the compass card or N.–S. damping filaments on the magnet system (card error).

The latter will never exceed 1° in a modern compass and is therefore unimportant. The lubber line may, however, be several degrees out of position and so cause an " *apparent* A," which is indistinguishable from the true coefficient A due to soft iron, known as " *real* A."

Coefficient A is calculated by the following formula :—

$$A = \frac{\text{Sum of 8 deviations on N, N.E., E., S.E., S., S.W., W., N.W.}}{8}$$

To calculate A from the deviations given above :—

$$A = \frac{+7+4-2-5-3+1+5+9}{8} = \frac{26-10}{8} = \frac{+16}{8} = +2°$$

Whether A be real or apparent, the method of correction is the same in P type compasses. To correct $+A$, turn the compass round *clockwise* : to correct $-A$, turn the compass *anti-clockwise*.

In the example, since the value of A is + 2°, the method of correcting would be to loosen the bolts holding the compass, turn it 2° clockwise (reading the 2° from the compass) and then secure the instrument again.

(iii) In O type compasses, although courses are read from a lubber line, bearings are read direct from the compass card through the sighting device and are thus unaffected by incorrect positioning of the lubber line. Errors in bearing will consequently be caused by " real A " only. " Apparent A " should therefore be eliminated by ensuring that the compass is correctly aligned in the aircraft so that the readings of both courses and bearings shall be affected by " real A " only, which, although it cannot be corrected, can be calculated and allowed for. The alignment is carried out as follows :—

(*a*) Place the aircraft in flying position and turn it until its longitudinal axis is in line with some distant object.

(*b*) Rotate the azimuth circle of the bearing compass until the sights are in line with the lubber line. Lock the azimuth circle.

(*c*) Rotate the compass and its standard until the sights are in line with the object dead ahead of the aircraft.

(*d*) Lock the standard in position.

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(iv) Coefficient B is due to a combination of the hard iron component P with a vertical soft iron component having exactly the same effect as P. The deviation is maximum on East and West and zero on North and South. Coefficient B is calculated from the formula :—

$$B = \frac{\text{deviation on East} - \text{deviation on West}}{2}$$

To calculate B from the example,

$$B = \frac{(-2) - (+5)}{2} = \frac{-7}{2} = -3\tfrac{1}{2}^\circ$$

The rules for correcting B are :—

To correct + B, use corrector magnets fore and aft with *red ends forward ;* or, if an adjustable corrector is fitted, insert the key in either of the fore and aft heads and turn *anti-clockwise.*

To correct — B, use corrector magnets fore and aft with *red ends aft,* or turn the key of the adjustable corrector *clockwise.*

Correction is carried out when the aircraft is heading East or West.

In the example, corrector magnets would be inserted in the corrector box, red ends aft, until the compass reading changes by $3\frac{1}{2}^\circ$ as nearly as possible.

(v) Coefficient C is due to a combination of the hard iron component Q with a vertical soft iron component having exactly the same effect as Q. The deviation is maximum on North and South and zero on East and West.

Coefficient C is calculated from the formula :—

$$C = \frac{\text{deviation on North} - \text{deviation on South}}{2}$$

To calculate C from the example,

$$C = \frac{(+7) - (-3)}{2} = \frac{+10}{2} = +5^\circ$$

The rules for correcting C are :—

To correct + C, use corrector magnets athwartships with *red ends* to *starboard ;* or, if an adjustable corrector is fitted, insert the key in either of the athwartships heads and turn *anti-clockwise.*

To correct — C, use corrector magnets athwartships with *red ends* to *port,* or turn the key of the adjustable corrector *clockwise.*

Correction is carried out when the aircraft is heading North or South.

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In the example, corrector magnets would be inserted in the corrector box, red ends to starboard, until the compass reading changes by 5° as nearly as possible.

(vi) Coefficients D and E are both due entirely to horizontal soft iron magnetism. Coefficient D has its maximum effect on the quadrantal points and coefficient E has its maximum effect on the cardinal points. Neither is of particular importance in aircraft compasses, and neither can be corrected. A small coefficient D is sometimes found, causing small deviations on the quadrantal points to remain after A, B and C have been corrected, but E is rare.

(vii) Figs. 88 to 92 show in the form of graphs how the effects of the five coefficients vary with the course of the aircraft. It will be noticed that, in the case of coefficients B and C, the deviations on the quadrantal points amount to approximately 0·7 of the maximum values. The deviation of the compass on any course is the combination of the deviations due to each coefficient on that heading, and is given by the formula :—Deviation = A + B sin Course + C cos Course + D sin 2 Course + E cos 2 Course.

A typical deviation curve is shown in Fig. 95.

### 5. Changes of deviation

(i) It was at one time thought that there was a considerable difference beween the deviations of a compass in an aircraft in flight and the deviations on the ground. Investigation has shown, however, that the magnetism of an aircraft does not change appreciably, and that variations of the deviation in the air are due to mechanical disturbances of the magnet system. On the other hand it must be remembered that alterations to the structure or equipment of an aircraft, such as changing an engine, removing a machine gun, repairing a steel longeron, and so on, will involve changes in the hard iron magnetism of the aircraft. Also, the magnetism of the various magnetic items may be subject to small and gradual changes owing to prolonged vibration during flight. For these reasons, deviations must be periodically checked and the compass adjusted if necessary. The occasions on which this must be carried out are laid down in K.R. & A.C.I., para. 762.

(ii) Changes of deviation are also caused by a change of magnetic latitude.

The direction taken up by a compass needle is the resultant of the directive force acting on it and the disturbing force due to the magnetism of the aircraft. The directive force is the horizontal component H of the earth's magnetic field, the value of which varies from zero at the magnetic poles to a maximum on the magnetic equator.

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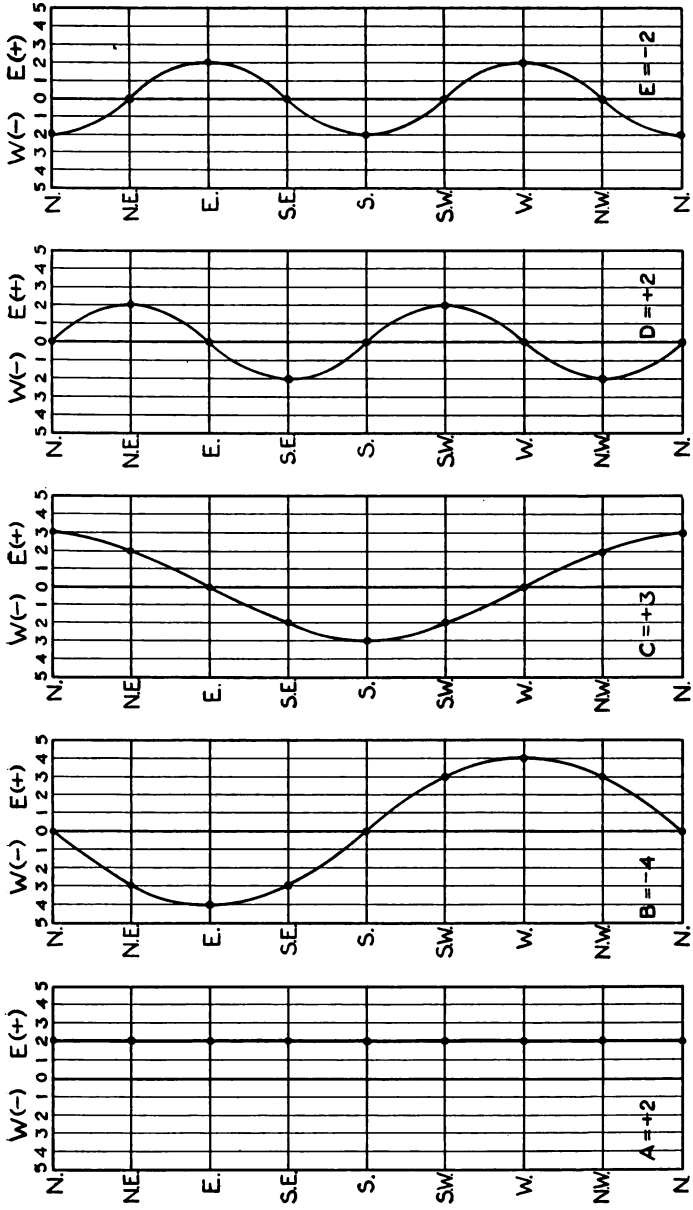


FIG. 88. Coefficient A.

FIG. 89. Coefficient B.

FIG. 90. Coefficient C.

FIG. 91. Coefficient D.

FIG. 92. Coefficient E.

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Assuming the hard iron magnetism to remain constant, its effect on the compass will increase if H becomes less and vice versa, i.e., the deviation due to hard iron magnetism will vary inversely as H. If, however, this deviation is completely corrected by means of corrector magnets in one magnetic latitude, it will be completely corrected in all other magnetic latitudes.

In the case of the soft iron magnetism, the value of the horizontal components depends directly on H and, since the directive force acting on the compass needle also depends directly on H, both the directive and the disturbing forces vary in the same ratio. Thus a change of H will cause no change of deviation. Hence coefficients A, D and E will remain unaltered. The value of the vertical soft iron components, however, depends on the vertical force Z, the value of which varied from zero at the magnetic equator to a maximum at the magnetic poles, and their effect on the compass will therefore vary directly as Z and inversely as H, i.e., as Z/H.

Coefficients B and C are due to a combination of hard iron and vertical soft iron components, but are corrected as though they were only due to hard iron magnetism. The effect of the soft iron varies with change of magnetic latitude in a different ration to that of the hard iron, and therefore coefficients B and C that have been corrected in a given magnetic latitude will not be properly corrected elsewhere.

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## CHAPTER XV.—PRACTICAL COMPASS ADJUSTMENT

### 1. Precautions before swinging an aircraft

The following precautions should be observed before beginning adjustment of the compass :—

(i) Test the compasses in the aircraft, and if defects are found, remedy them or replace the faulty instrument. (*See* chapter XIII, para. 8).

(ii) Ensure that a corrector device is mounted directly below the centre of each compass and is properly aligned. (*See* chapter XIII, para. 9 (vi)).

(iii) If bearing compasses are to be adjusted, they must be properly aligned before the swing is commenced. (*See* chapter XIV, para. 4 (iii)).

(iv) Ensure that all equipment which could possibly affect the compass and which is normally carried during flight (e.g. guns, W/T apparatus, etc.) is in position, and that all equipment (tools, etc.) which is not carried during flight is removed.

(v) See that the following articles are available for use during the swing :—corrector magnets (or key for adjustable correctors), spanner to fit compass holding down bolts, screwdriver (to remove corrector box covers).

Details of the swing should be recorded on a prepared form. The form illustrated in Fig. 93 is recommended for use when swinging on a compass base, but when using a landing compass a form similar to that shown in Fig. 96 should be used.

### 2. Points to be noted when swinging an aircraft

(i) It is advisable to adopt a definite sequence when swinging an aircraft : time and work can be economised by following a routine.

(ii) If more than one compass is fitted, corrections to all compasses should be made before the aircraft is moved.

(iii) Tools and corrector magnets must be kept well away from the compasses during the swing.

(iv) Where electrical circuits run near any compass, e.g. in aircraft equipped for night flying, the circuits should be switched on and off on each heading in order to insure that they do not set up magnetic fields which will affect the compass.

(v) Compasses should be given time to settle down after a change of heading : they may be assisted by gentle tapping of the compass bowl.

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### 3. Swinging on a compass base

(i) The following sequence of operations is recommended :—

(*a*) Plumb bobs should be hung from the centre of the airscrew boss and the tail skid in order to facilitate alignment on the headings marked on the base.

(*b*) Put the aircraft and its controls in flying position and align carefully on magnetic N. Enter the compass reading in the " First Reading " column of the prepared form (*see* Fig. 93).

AIRCRAFT TYPE AND No: ...Hart K7372.....

COMPASS TYPE AND No: ...P.4. N°2056 H.....

DATE...13-1-35..... ADJUSTED BY. F/O. J. Smith.

| AIRCRAFT'S HEAD | FIRST READING | DEV. | CORRECTED READING | DEV. | FINAL READING | DEV. |
|---|---|---|---|---|---|---|
| N. 000° | 358° | +2° | 001° | -1° | 359° | +1° |
| NE. 045° | | | 047° | -2° | 045° | 0° |
| E. 090° | 098° | -8° | 092° | -2° | 090° | 0° |
| SE. 135° | | | 136° | -1° | 134° | +1° |
| S. 180° | 184° | -4° | 181° | -1° | 179° | +1° |
| SW. 225° | | | 228° | -3° | 226° | -1° |
| W. 270° | 266° | +4° | 272° | -2° | 270° | 0° |
| NW. 315° | | | 316° | -1° | 314° | +1° |

Coeff. C = $\frac{N - S}{2}$ = $\frac{+2+4}{2}$ = +3°...1.. Magnets...1/32....Red pole..Starboard

Coeff. B = $\frac{E - W}{2}$ = $\frac{-8-4}{2}$ = -6° ..2..Magnets...1/32....Red pole..Aft.....

Coeff. A = $\frac{-13}{8}$ = $-1\frac{5}{8}$° Turn Compass 2°...Anticlockwise.....

FIG. 93.—Form for use when swinging on a compass base.

(*c*) Place the aircraft heading E. Enter the compass reading in the " First Reading " column.

(*d*) Place the aircraft heading S. Enter the compass reading in the " First Reading " column. Calculate and correct for coefficient C. In the example illustrated in Fig. 93, coeff. C = $\frac{\text{devn. on N.} - \text{devn. on S.}}{2}$ = $\frac{+2+4}{2}$ = +3°. Corrector magnets are therefore placed athwartships in the corrector box, with red ends to starboard, or the key of the adjustable corrector inserted in

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one of the athwartships heads and turned anti-clockwise, until the reading of the compass alters by 3° as nearly as possible, i.e. until the compass reads 181°. Enter corrected compass reading on S (*see* Fig. 93).

(*e*) Place the aircraft heading W. Enter the compass reading in the " First Reading " column. Calculate and correct for coefficient B. In the example, coeff. B = $\frac{\text{devn. on E.} - \text{devn. on W.}}{2} = \frac{-8-4}{2} = -6°$. Corrector magnets are therefore placed fore and aft in the corrector box, with red ends aft, or the key of the adjustable corrector inserted in one of the fore and aft heads and turned clockwise, until the reading of the compass alters by 6° as nearly as possible, i.e. until the compass reads 272°. Enter corrected compass reading on W.

(*f*) Place the aircraft successively on N.W., N., N.E., E., S.E. and S.W. and enter corrected readings. (*Note* :— On N. and E. the " First Readings " should have changed by the same amounts as on S. and W. respectively.) If a large coefficient B has been corrected on W., the reading on S. should be checked (*see* para. 4 (iv) of this chapter).

(*g*) Calculate coefficient A from corrected readings and correct for it if necessary. In the example, the deviations on the 8 cardinal and quadrantal points after correction are :— −1, −2, −2, −1, −1, −3, −2, −1. Then coeff. A = $-\frac{13}{8} = -1\frac{5}{8}°$. The compass is therefore turned through 2° anti-clockwise (*see* chapter XIV, para. 4 (ii)). Complete the " Final Reading " column of the form.

(*h*) Secure the corrector boxes or operating heads of adjustable correctors.

(*i*) Enter all particulars in the Squadron Compass Log Book (Form 343). Where a coefficient A has been corrected, the " Final Readings " are entered in the last column of the compass log book, the details of corrector magnets being recorded under " Remarks " (*see* Fig. 94).

(*j*) Fill in completely (i.e. on both sides) a deviation card for each compass and mount it near the appropriate compass. It is usually preferable to use Form 316 (Fig. 6) for P-type compasses and Form 316A (Fig. 7) for O-type compasses.

(ii) It will be noticed in Fig. 94 that there is a small amount of residual deviation after coefficients A, B and C have been corrected. If coefficients D and E are calculated, it will be found that their values are $-\frac{3}{4}°$ and $+\frac{1}{2}°$ respectively. Thus it might be stated that the deviations remaining after completion of the swing were due to soft iron magnetism in the

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Squadron No. 286 (B) Flight "C"

Adjustment made at Abingdon.

Date of Adjustment 13-1-35.

Type of Aeroplane Hart.

Number of Aeroplane K7372

Type of Compass P.4.

Number of Compass 2056. H.

| | First Reading | Corrected Reading | ~~Number and Disposition of Adjusting Magnets~~ Final Reading |
|---|---|---|---|
| N. (0°) | 358° | 001° | 359° |
| N.E. (45°) | | 047° | 045° |
| E. (90°) | 098° | 092° | 090° |
| S.E. (135°) | | 136° | 134° |
| S. (180°) | 184° | 181° | 179° |
| S.W. (225°) | | 228° | 226° |
| W. (270°) | 266° | 272° | 270° |
| N.W. (315°) | | 316° | 314° |

Adjustment made and Deviation Card fitted by—

*Signature*

J. Smith. F/O

REMARKS 1 magnet 1/32 red pole to starboard.
2 magnets 1/32 red pole aft.
Coefficient A(-2°) corrected.

FIG. 94.—Compass log book.

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aircraft. On the other hand it should be remembered that aircraft compasses can only be read to an accuracy of 1°, that a magnet system, after deflection, may not return exactly to its original position, and that parallax may cause an error which is similar in its effect to a coefficient D (*see* para. 6 (iv) of this chapter). A residual error of the order of 1° on any heading is, therefore, not unusual, and is not necessarily due to soft iron magnetism.

(iii) In certain types of all-steel aircraft, where large and irregular deviations are suspected, it may be advisable to obtain the deviations on sixteen points instead of on eight. Thus, after correction of coefficients B and C, the aircraft would be placed on W.N.W., N.W., N.N.W., N., etc., and the readings recorded.

**4. Correction of coefficients**

(i) When correcting for small deviations with corrector magnets, difficulty is sometimes experienced in finding magnets with a sufficiently small magnetic moment. The desired effect can usually be obtained by one of the following methods :—

(*a*) Place two magnets of the same thickness in the same hole of the corrector box but with the poles opposed to one another. A small magnetic effect can also be obtained by using two equally strong magnets opposed to one another but placed in different holes at different distances from the magnet system.

(*b*) The magnetic moment of a thin magnet can often be reduced by bending it backwards and forwards several times. Tapping the magnet will produce a similar result.

(*c*) As a last resort, the magnetic moment can be reduced by breaking off a portion of the magnet. The portion to be used should be wrapped in paper in such a manner as to prevent it from moving about in the corrector box.

(ii) Correction for coefficient A can be carried out on any heading. The effect of correcting a + A (i.e. turning the compass clockwise) is to increase the readings on all headings by the same amount, while correction of −A decreases all the readings. In the example illustrated in Fig. 93, suppose the compass was reading 165°, the verge ring would be set to 163° and clamped, the securing bolts loosened, and the compass turned until the N.-S. damping filament was parallel to the grid wires. The securing bolts would then be tightened.

(iii) Some difficulty may be found in remembering which way the magnets should be inserted in the corrector box or

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which operating heads should be used in the adjustable corrector. Several useful aids to memory have been devised, of which the following may be found particularly useful

A B C
C F S

The meaning of this is as follows :—

To correct + *A*, turn compass *Clockwise.*

To correct + *B*, use magnets with red ends *Forward.*

To correct + *C*, use magnets with red ends to *Starboard.*

When an adjustable corrector is used, the key is always inserted in an E.-W. direction, i.e. at right angles to the grid wires on the compass. To correct a + B or + C, the key should be turned *anti-clockwise,* and to correct a — B or — C, the key should be turned *clockwise.* Adjustable corrector devices require delicate handling, as a small movement of the key causes a large effect on the magnet system.

(iv) It must be remembered that, although coefficient B causes no deviation on N. or S., a large coefficient may have an effect on the deviation on N. and S. by causing an apparent increase or decrease of the directive force acting on the magnet system (*see* chapter XIV, para. 5 (ii)). Similar arguments apply to the effect of coefficient C on the deviation on E. and W. For this reason, when a swing is carried out as detailed in para. 3 above, it may be found that the corrected readings on N. and E. do not agree with the values expected after correction on S. and W., and that the corrected reading on S. changes after correction of coefficient B on W. It may, therefore, be found on completing the swing that the coefficients have not been completely corrected. Hence it is advisable to reduce large coefficients by rough correction before commencing the detailed swing. If a large deviation—say over 10°—is found to exist on N., it should be roughly corrected by a magnet placed athwartships in the corrector box, or by means of one of the athwartships operating heads of the adjustable corrector. If a large deviation is found on E., it should be roughly corrected by a magnet placed fore and aft or by means of one of the fore and aft operating heads.

### 5. Simplified method of compass adjustment

(i) When adjustable corrector devices are fitted, a simplified method of swinging aircraft may be used. This method is as follows :—

(*a*) Place the aircraft heading N. Correct *all* the observed deviation.

(*b*) Place the aircraft heading E. Correct *all* the observed deviation.

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(*c*) Place the aircraft heading S. Correct *half* of the observed deviation. Enter the corrected reading in the compass log book.

(*d*) Place the aircraft heading W. Correct *half* of the observed deviation. Enter the corrected reading in the compass log book.

(*e*) Place the aircraft successively on the following points and enter the compass reading on each point in the compass log book :—

N.W., N., N.E., E., S.E., S.W.

If much coefficient B has been corrected on W., the reading on S. should be checked.

(*f*) Calculate coefficient A from the corrected readings and correct for it if necessary (*see* chapter XIV, para. 4 (ii)).

(*g*) Complete compass log book and deviation cards (*see* para. 3 (i) of this chapter).

(ii) This method does away with all calculation, except that of coefficient A. It can be used with corrector boxes and magnets, but it is not so convenient in this case owing to the number of adjustments which may have to be made and the difficulty of obtaining the required fineness of adjustment.

(iii) For reasons outlined in para. 4 (iv) above, the swing should be commenced on E. instead of N. if in any type of aircraft much deviation is found on E. and W.

### 6. Swinging by means of a landing compass

(i) A swinging base is a convenient adjunct to swinging small and medium aircraft, but it is advisable not to use it for large aircraft owing to the time and labour involved in placing the aircraft so that its longitudinal axis lies exactly over one of the lines marked on the base.

The following consideration is of importance. Suppose an aircraft is heading, say, 358° instead of magnetic north, is there any need to man-handle or otherwise move it through 2° in order that the deviation on north may be observed? Fig. 95 shows a typical deviation curve before correction ; the maximum deviation is 14°. The dotted lines indicate courses which differ from the cardinals and quadrantals by 4°. It will be seen that the deviation on any of these courses does not differ from that on the cardinal or quadrantal points by more than 1°, while on east and west there is no sensible error.

Hence it may be stated that, provided the maximum deviation does not exceed 10°, an error of alignment of not more than 4° will not sensibly affect the accuracy of the swing. Every effort should be made, naturally, to align an aircraft as time and other circumstances permit on any required course.



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(ii) The following method is adopted for swinging large aircraft, and may also be used for small aircraft :—

The aircraft is headed approximately on the required magnetic courses by its own engines or by other means and by reference to its own compass (unless the deviations are very large and their values are quite unknown). The correct magnetic headings are measured by means of a landing compass. The adjuster should remain in the

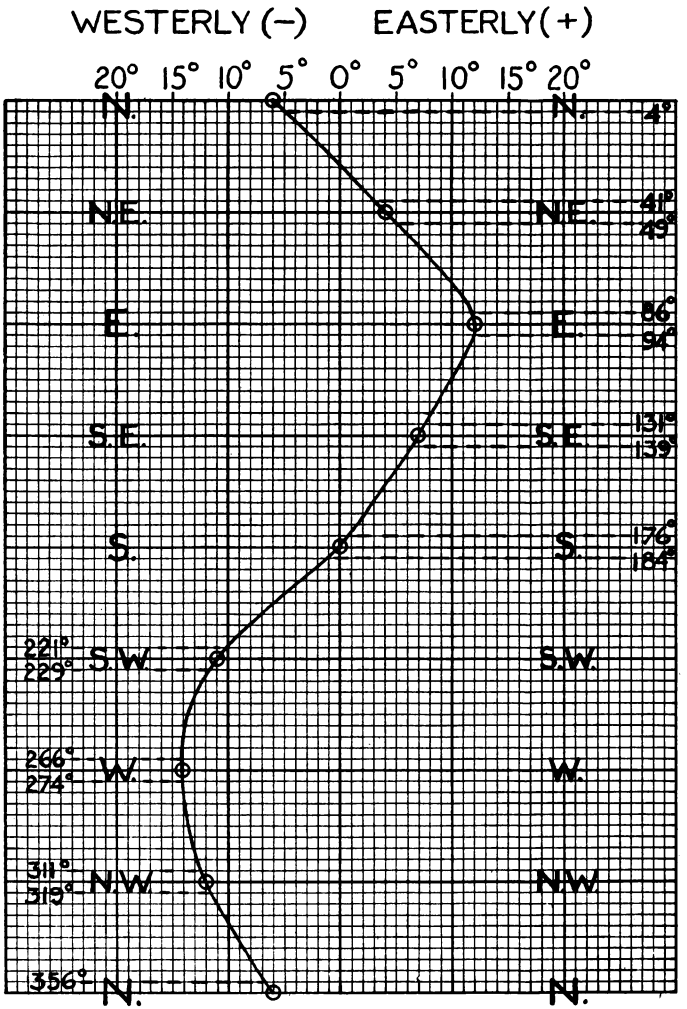


FIG. 95.—Deviation curve before correction.

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cockpit of his aircraft while an assistance uses the landing compass. The type of landing compass in common use in the Royal Air Force is the "Landing Compass, Medium" (Stores Ref. No. 6A/O.34) (*see* chapter XIII, para. 5 (viii)). To take a bearing, the observer stands exactly behind the aircraft at a convenient distance and aligns the sighting device up the centre-line of the fuselage. Alternatively, particularly if the rudder of the aircraft is

AIRCRAFT TYPE AND No:.....Avro Anson. K.6685.....

COMPASS TYPE AND No:.....P.4. No.3628.H.*.....

DATE....26-2-35.....ADJUSTED BY..Flt. P. Snodgrass.

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|
| | FIRST READING | | | CORRECTED READING | | | AIRCRAFT'S COMPASS ON POINTS IN COL. (1) | | |
| | LANDING * COMPASS | AIRCRAFT'S COMPASS | DEV. | LANDING * COMPASS | AIRCRAFT'S COMPASS | DEV. | BEFORE CORRECTION OF COEFF. A. | AFTER CORRECTION OF COEFF. A. | FINAL DEV. |
| N.000° | 359° | 001° | -2° | 001° | 000° | +1° | 359° | 000° | 0° |
| NE.045° | | | | 045° | 044° | +1° | 044° | 045° | 0° |
| E. 090° | 093° | 086° | +7° | 091° | 089° | +2° | 088° | 089° | +1° |
| SE.135° | | | | 133° | 131° | +2° | 133° | 134° | +1° |
| S. 180° | 182° | 179° | +3° | 182° | 182° | 0° | 180° | 181° | -1° |
| SW.225° | | | | 224° | 224° | 0° | 225° | 226° | -1° |
| W. 270° | 267° | 271° | -4° | 267° | 266° | +1° | 269° | 270° | 0° |
| NW.315° | | | | 316° | 314° | +2° | 313° | 314° | +1° |

* If Landing Compass is used ahead of aircraft add or subtract 180°.

Coeff. C = $\frac{N - S}{2} = \frac{-2-3}{2} = -2\frac{1}{2}°$ .....2.....Magnets...1/50.....Red pole..port.....

Coeff. B = $\frac{E - W}{2} = \frac{+7+4}{2} = +5\frac{1}{2}°$ ....2....Magnets...1/32.....Red pole..forward...

Coeff. A = $\frac{+9}{8} = +1\frac{1}{8}°$ Turn Compass.....1° clockwise.....

FIG. 96.—Form for use when swinging with a landing compass.



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off-set, the landing compass may be set up in front of the aircraft. In this case the bearing registered by the landing compass is the reciprocal of the aircraft's course.

(iii) The sequence of operations is as described in para. 3 above, except that a form similar to that shown in Fig. 96 should be used for recording details of the swing. The actual magnetic headings of the aircraft are not those shown in the first column, but are the readings of the landing compass as entered in columns 2 and 5. The difference between this reading and the reading of the pilot's or observer's compass gives the deviation on the magnetic heading which, as explained above, can be taken as the deviation on the required cardinal or quadrantal point. After the corrected readings and deviations have been entered, the corrected readings should be converted to the readings that would have been observed had the aircraft been heading exactly on the cardinal and quadrantal points, and entered on column 8. For example, if the compass read 183° on a heading of 184°, it would read 179° on a heading of 180°. Examination of Fig. 96 should make the procedure clear.

(iv) When an aircraft is swung " tail down ", i.e. when it is taxied on the various headings by its own engines, the longitudinal axis may be included to the horizontal by as much as 10–15 degrees. This is liable to give rise to errors, since (*a*) the magnetism of the aircraft is not distributed relative to the compass needle as it will be in flight, and (*b*) a parallax error is introduced in reading courses from grid steering types of compass. The former error has been found by investigation to be small in aircraft where the compass position has been well chosen, but the latter may be large, particularly on the quadrantal points, where it may be as much as 8°. Errors on the quadrantal points give the effect of a negative coefficient D. Care must, therefore, be taken when reading the compass during a swing of this type that the observer's eye is as nearly as possible directly over the centre of the compass.

### 7. Swinging an aircraft afloat

(i) As a general rule, the compasses of an aircraft should not be corrected when it is afloat, as even under the most favourable conditions of wind and tide the necessary degree of accuracy is difficult to obtain. Swinging should be carried out whenever possible on a turntable ashore, but it may occasionally be necessary or convenient to check the deviations when the aircraft is afloat, normally moored at a buoy. The essential problem is to determine the correct magnetic heading of the aircraft at a given moment.

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(ii) One method is to take bearing of a distant object by means of a bearing compass or bearing plate. An object should be selected at a suitable distance and its magnetic bearing from the buoy should be determined from a chart. As a rough guide it may be mentioned that if the selected object be three miles distant from the buoy and the aircraft can move round a circle of twenty yards diameter, the maximum change of bearing due to alteration of the position of the aircraft will be of the order of $\frac{1}{4}°$.

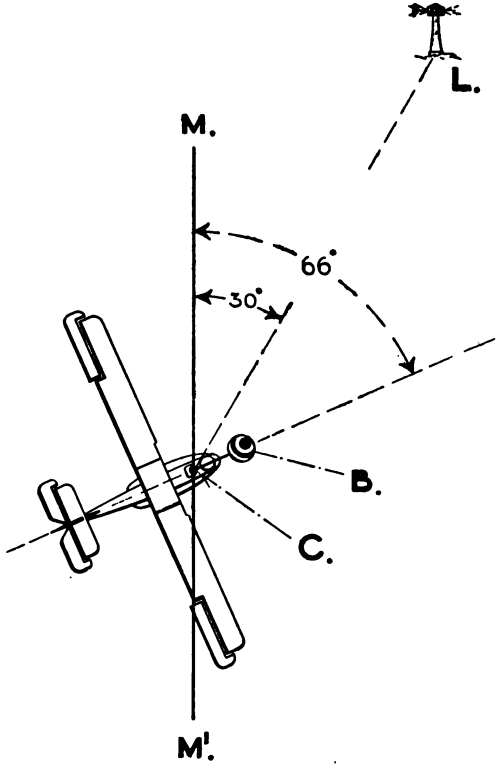


FIG. 97.—Swinging an aircraft afloat by bearing compass.

Suppose the object selected to be a lighthouse—L in Fig. 97—and the magnetic bearing of L from the buoy B is 030°. Then suppose that a bearing of L is found to be 034° by bearing compass at the moment when the heading of the aircraft, as given by the bearing compass, is 070°. It follows that a deviation of −4° exists, and this is the deviation on a course of 070° by compass. Hence the magnetic heading of the aircraft when the bearing was taken was 066°, and if the

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reading of the pilot's compass was taken at the same moment as the bearing, the deviation of the pilot's compass on the particular heading can be determined (*see* example in chapter I, para. 7 (vii)). In order that a deviation card may be prepared, deviations should be obtained on at least eight

| (1) KNOWN MAGNETIC BEARING OF DISTANT OBJECT | (2) BEARING BY BEARING COMPASS. | (3) BEARING COMPASS DEVIATION | (4) COURSE BY BEARING COMPASS. | (5) CORRECT MAGNETIC COURSE. | (6) COURSE BY PILOT'S COMPASS. | (7) PILOT'S COMPASS DEVIATION. |
|---|---|---|---|---|---|---|
| 030° | 030° | 0° | 296° | 296° | 292° | +4° |
| 030° | 031° | -1° | 329° | 328° | 326° | +2° |
| 223° | 226° | -3° | 355° | 352° | 353° | -1° |
| 223° | 226° | -3° | 038° | 035° | 039° | -4° |
| 223° | 223° | 0° | 078° | 078° | 083° | -5° |
| 030° | 028° | +2° | 134° | 136° | 139° | -3° |
| 030° | 027° | +3° | 168° | 171° | 171° | 0° |
| 030° | 026° | +4° | 208° | 212° | 209° | +3° |
| 030° | 028° | +2° | 262° | 264° | 259° | +5° |

FIG. 98.—Swing of aircraft afloat.

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headings. The deviations are then plotted as a graph on Form 316a or elsewhere. In order to place the aircraft on the various headings, the tail is towed round by a motor boat. Under these conditions, and by reason of the effect of wind and tidal currents, it will not be possible to hold the aircraft steady on any heading for an appreciable time, and thus it is essential that all observations should be taken at the same moment on a pre-arranged signal. When a bearing compass is mounted in a rear cockpit, it is not usually possible to take bearings of objects dead ahead, and therefore it may be necessary to select a second distant object so that it will be possible, on any heading, to take a bearing of one of them.

(iii) Details of a typical swing of an aircraft afloat are given in Fig. 98. A prepared form should be used as shown.

The deviation curve for the pilot's compass can be plotted from columns (5) and (7) and for the bearing compass from columns (5) and (3).

Fig. 99 shows the deviations of the pilot's compass plotted on Form 316a.

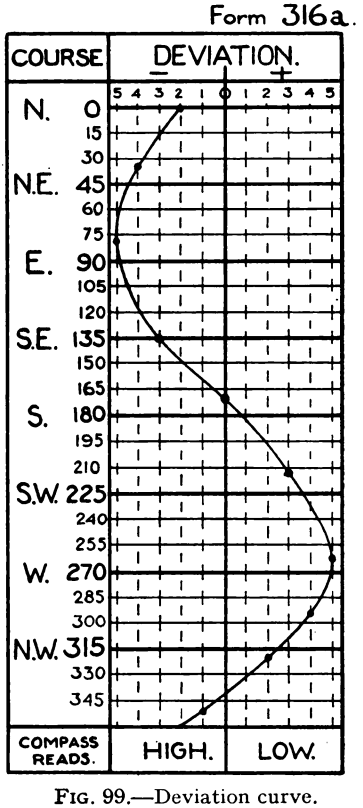


FIG. 99.—Deviation curve.

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If deviations of the pilot's compass on the cardinal and quadrantal points are required in order that Form 316 may be completed, they are read from the graph shown in Fig. 99, and the deviation card made out as follows :—

| *For Magnetic Course.* | *Steer by Compass.* |
|---|---|
| N. 000° .. .. .. | 002° |
| N.E. 045° .. .. .. | 049° |
| E. 090° .. .. .. | 095° |
| S.E. 135° .. .. .. | 138° |
| S. 180° .. .. .. | 179° |
| S.W. 225° .. .. .. | 221° |
| W. 270° .. .. .. | 265° |
| N.W. 315° .. .. .. | 312° |

For the reason given in sub-para. (i) corrections are not normally applied if the deviations are small. The values of the coefficients may, however, be calculated from the graph. In certain circumstances, if large deviations are found, it may be desirable to make approximate corrections for coefficients B and C with the aircraft heading as nearly as possible E. or W. and N. or S. respectively. The complete swing will then have to be repeated, in order that the corrected deviations may be obtained and the new deviation curve plotted.

(iv) An alternative method of swinging an aircraft afloat is to mount a landing compass ashore on a site free from local magnetic fields and to take simultaneously bearings of the bearing compass in the aircraft from the landing compass and of the landing compass from the aircraft. The method of calculating the deviations on the various headings is exactly the same as described above, but instead of " Known Magnetic Bearing of Distant Object " in column (1) of Fig. 98 the reciprocals of the landing compass readings will be entered. For example, if the landing compass reads 100°, the correct magnetic bearing of the landing compass from the bearing compass in the aircraft is $(100° + 180°) = 280°$.

### 8. Swinging an aircraft in the air

(i) The deviations of a compass in the air should not differ from the deviations on the ground. In certain circumstances, however, it is possible that electrical equipment may cause a deviation when the aircraft is in flight, although that deviation was not apparent on the ground. This should never occur when standard equipment is fitted in the correct position in the aircraft, but may occur when any special apparatus is being tested. Under these circumstances or if there is any doubt of the effects of any electrical equipment on the compass, it is essential that a check of the errors recorded on the ground

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should be made by a test flight. During this check the instrument lighting, wireless generator and any other electrical apparatus fitted should be switched on and off in order to ensure that they have no effect on the compass, a steady course being maintained by steering on a cloud or distant object, or by the sun. This should be carried out on a northerly or southerly course and on an easterly or westerly course.

When an aircraft is fitted with two or more compasses, a quick way of finding out whether electrical equipment is causing a deviation in any of the compasses is as follows. Fly the aircraft on a steady course and compare the readings of the compasses, after making allowances for any recorded deviations. If the readings are the same, it can be assumed that the electrical equipment is not affecting the compasses, since an electrical disturbance cannot cause exactly the same deviation in all the compasses at the same time. This method is only useful for detecting the presence of any disturbing force and is useless for checking the actual deviation involved.

Care should be taken not to confuse deviation due to electrical apparatus with the temporary deviation due to mechanical disturbance consequent upon slight changes of course or speed (*see* chapter XIII, para. 4 (viii) ).

(ii) It will generally be undesirable to attempt to correct the compasses of an aircraft in the air, but it may sometimes be necessary to determine the deviations on sufficient courses to enable a deviation curve to be plotted ; also it will often be useful to check deviations during flight, particularly before a long cross-country or oversea flight. The problem is somewhat similar to that of swinging an aircraft at moorings. Either a bearing compass or bearing plate is essential for most of the methods available.

The correct course of the aircraft may be determined :—

(*a*) by observing the bearing by compass of two objects in transit,

(*b*) by taking azimuthal bearings of the sun,

(*c*) by reciprocal bearings of a landing compass or ship's compass,

(*d*) by a photographic method,

(*e*) by aligning the longitudinal axis of the aircraft on a known line of transit.

Owing to the inherent errors of the compass due to slight changes of course or speed it cannot be expected that the results will be as accurate as a swing on the ground, particularly in bumpy conditions. By reason of technical differences in construction, a bearing compass is more liable to errors than a pilot's type compass. A form similar to that shown in Fig. 98 should be prepared before commencing the swing, the known bearings being entered in the first column in each method.

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(iii) If the first method is to be used, the magnetic bearings of prominent objects in transit or of straight roads or railway lines should be taken from a map or chart. The aircraft is flown on a steady course across the line of transit and a bearing is taken by bearing compass along the line of transit at the moment when the aircraft crosses it. In the case of aircraft in ships at sea where there are no objects from which to obtain a transit bearing, transits of the ship's masts and wake should give good results providing that the ship is steering a steady course. The aircraft should be flown across the line of transit on at least eight different courses at approximately equal angular intervals as nearly as possible on the cardinal and quadrantal points, and the deviation recorded on each course. As in the case of swinging an aircraft afloat, it will usually be necessary to use at least two known transits. Deviations are then plotted in the form of a graph.

(iv) The second method is likely to give more accurate results, because the bearings obtained are not "snap" bearings, as in the first method. The observer takes a bearing of the sun, using the reflector and coloured glass shares of the bearing compass, reading the bearing and noting the exact time at the moment when the compass appears to be most steady. Before the flight is begun, the correct magnetic bearings of the sun should be tabulated for convenient time intervals (two minutes, for instance) or plotted as a graph, the true bearings being obtained from information contained in the Nautical Almanac and the Alt-Azimuth tables (*see* A.P. 1456—Manual of Air Navigation, Vol. II).

The disadvantage of this method is that it can only be used conveniently when the altitude of the sun is small, and swinging by this method must necessarily take place at some time near dawn or sunset. When the sun's altitude exceeds 30°, errors due to the aircraft not being in level flight when the bearing is taken become excessive.

(v) In the third method, the aircraft proceeds to a suitable distance, i.e., approximately visibility range, from the observer with the landing compass or from the ship, and on a pre-arranged signal, either by W/T or visual signals, simultaneous bearings are taken (*a*) of the aircraft from the landing compass or ship, and (*b*) of the landing compass or ship from the aircraft, on the various courses. This method is subject to possible errors due to the necessary signalling and the fact that the reciprocal bearings must be taken simultaneously.

(vi) The photographic method is somewhat similar to the transit method. A camera is mounted in the aircraft to take vertical photographs, and is very accurately aligned so that the fore and aft collimation marks, which appear on each photograph, shall be exactly parallel to the longitudinal axis

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of the aircraft. The aircraft is flown over a straight road or railway line, whose direction can be measured from a large-scale map, the courses being as nearly as possible on the cardinal and quadrantal points, and a photograph is taken on each course at the moment of crossing the road or railway. As each photograph is taken the course indicated by the compass is noted. When the photographs have been developed, the angle between the road or railway and the longitudinal axis of the aircraft can be measured from the prints, and hence the correct courses are known. The disadvantage of the method is that the deviations cannot be determined until the aircraft has landed and the photographs have been developed.

(vii) If the aircraft is either a single seater or has no bearing compass, the following method can be employed :—

A prominent object—say a building on the aerodrome—is selected and marked on a large-scale map. Four objects distant about three miles from the aerodrome and bearing approximately magnetic N. or S., N.E. or S.W., E. or W., N.W. or S.E. from the prominent building are now chosen. These objects must be easy to distinguish from the air : if there is a straight road or railway running in the desired direction, this will do just as well. The exact bearings of these objects from the aerodrome building are read from the map. The aircraft should then be flown so that its longitudinal axis is in line with each of the transits in turn. The compass reading should be taken and the difference between this and the measured bearing or its reciprocal will give the deviation on the course steered. Care must be taken to fly steady courses, and it must be realised that, unless the wind is dead ahead or astern on any course, the aircraft can only be placed momentarily with its longitudinal axis on the transit and cannot be flown along it.

### 9. Compass swinging bases

(i) A swinging base is generally in the form of a circular concrete platform, placed at the edge of an aerodrome well away from buildings, the magnetic directions N., N.E., E., S.E., etc., being marked by means of black painted lines radiating from the centre, and clearly lettered. The intermediate points N.N.E., E.N.E., etc., are marked in a similar way, but are not normally lettered.

It must be remembered that the magnetic variation is not constant, but changes at a fairly steady rate. In England the average change at present is about 1° in 5–6 years. For this reason compass swinging bases must be re-marked every few years.

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(ii) A swinging base, either permanent or temporary, may be laid out quite accurately by the use of a good landing compass. It is first necessary to select a suitable site, conveniently placed relatively to hangars and not likely to be in the path of aircraft taking off or landing, and free from local magnetic effects. The selected place should not be near considerable masses of iron, such as railway lines, water or petrol pipe systems, or iron or ferro-concrete structures of any kind. To check whether any local magnetic field exists at the site, bearings of distant objects should be taken from the site by landing compass and compared with magnetic bearings taken from a large-scale map of the district. The two sets of bearings should agree if the site is suitable. An alternative method, involving the use of two landing compasses, is to set up one landing compass on the site of the base and the other some distance—say, 200 yards—away. Bearings are taken from each instrument to the other one and, if the magnetic conditions of the site are satisfactory, one bearing will be the reciprocal of the other. The second bearing compass should be moved round a circle with the first as centre and eight or ten readings taken in all from each compass. If the base is to be permanent, a circular platform of concrete should be laid down on the selected site. A suitable size is a circle of radius 20 feet. To mark the base, a landing compass is set up in the centre. An assistant holds a rod vertically on the circumference of the circle and is directed how to move it until its bearing from the compass is exactly on some cardinal or quadrantal point. A peg is then driven into the ground at the foot of the rod. The operation is repeated until all the required directions are laid down. Strings are stretched between opposite pairs of pegs : these strings should intersect directly under the landing compass. Radiating lines from the centre to the pegs are then painted on the base and are lettered N., N.E., E., etc. The date should also be painted on the base.

(iii) In the case of a temporary base the landing compass is set up on the selected site and a circle of which the landing compass is the centre is marked on the ground. A suitable radius is 20 feet. The same procedure is followed as for laying out a permanent base : the radiating lines are marked on the ground by means of narrow chalk-filled trenches, wooden battens, or any other convenient method depending on the nature of the ground and the degree of permanence desired.

(iv) If iron or ferro-concrete structures of any kind are subsequently constructed, or pipe lines or electric cables laid in the neighbourhood of the base, the site should be re-checked to see that it is free from any local magnetic effects.

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**AIR PUBLICATION 1234**
(*Revised April*, 1935)

## CHAPTER XVI.—DIRECTION FINDING WIRELESS TELEGRAPHY

### 1. Directional properties of aerials

(i) A wireless aerial sends out energy in the form of waves which travel over the earth's surface along arcs of great circles and which set up voltages in all conductors which lie in their paths. The voltages set up in a conductor vary as a sine curve. Suppose that in Fig. 100 vertical aerials *a*, *b*, *c*, *d* and *e* are set up as shown in the path of a wireless wave. If positive charges be represented above and negative charges below the horizontal line, then it is seen that aerials *a*, *c* and *e* have no charge, while *b* has the maximum positive charge and *d* the maximum negative charge at a given instant. If next a single aerial lying in the path of a wireless wave be considered, it can be seen that at some instant the aerial will not be charged. Then a positive charge will start from zero, increase to its maximum value, and decrease to zero again. Following this, a negative charge will increase to its maximum value and decrease to zero, the whole cycle of operations being repeated a large number of times in a second.

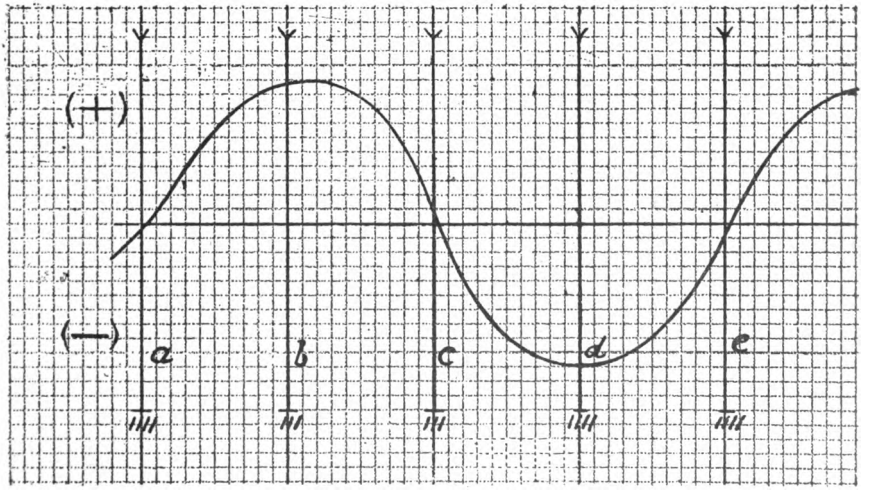


FIG. 100.—W/T aerials in path of wireless wave.

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(ii) Next consider two vertical aerials A and B, connected together at the top and bottom, and so forming a loop. Imagine the two aerials to be placed one immediately behind the other in the path of a wave, as shown in Fig. 101. It is seen that at the instant being considered the voltage in aerial A is greater than that in aerial B. Now when a difference of voltage exists in an electrical circuit a current flows from the point of higher to the point of lower voltage : thus a current is set up in the loop aerial. Suppose next that the aerial be

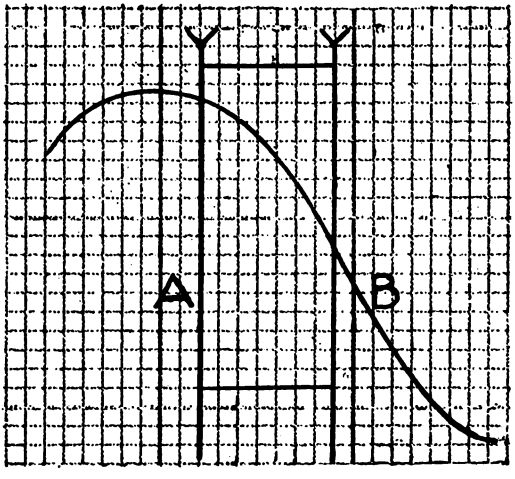


FIG. 101.—Loop aerial in path of wireless wave.

turned around a vertical axis through 90° so that the loop is placed at right angles to the path of the wave. In this position precisely the same voltage (both in magnitude and direction) would be set up in A and B at any given instant. Then, since there would be no difference of voltage, no current would flow. It should now be apparent that the current generated in any given loop aerial by a wireless wave is changed when the direction of the aerial relative to the path of the wave is changed.

(iii) Consider a loop aerial which can be rotated about a vertical axis as shown in plan in Fig. 102 as AB. Suppose the aerial be rotated so that A occupies successively the positions marked A1, A2, etc. Then the current generated in the aerial in its various positions relative to the direction of the wave may be represented by the curve XYZ. It will be seen that the curve takes the form of a cosine curve. Expressed generally, the current generated in the aerial varies as the

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cosine of the angle between the direction of the wave and the direction of the aerial. It now appears that a loop aerial is an elementary direction-finding apparatus. Suppose that a known W/T station were transmitting (Paris for instance).

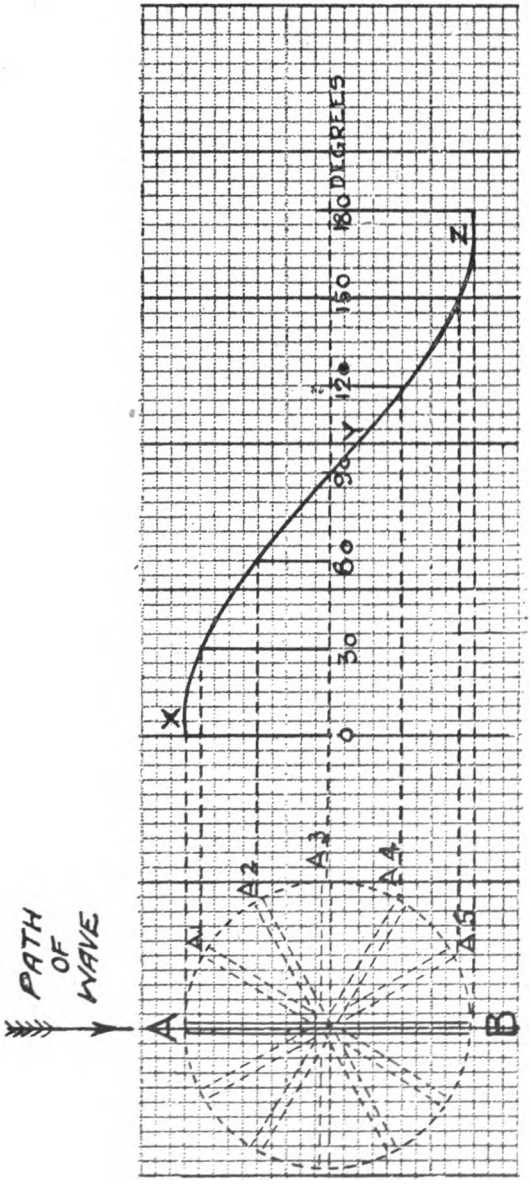


FIG. 102.—Cosine curve of current in aerial.

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Then if a loop aerial be turned until it is known that the maximum current is flowing in it, it follows that the direction of the aerial indicates the great circle bearing of Paris. The amount of current flowing can be conveniently determined by suitably connecting telephones to the aerial circuit. Thus, when the aerial lies at right angles to the path of the wave, no sound will be heard in the telephones, but as the aerial is turned, the signals will become louder until the maximum sound is heard when the aerial lies exactly in the path of the wave.

(iv) Consideration of the cosine curve shows that the value of the cosine changes slowly about the position of its maximum values (0° and 180°) and much more rapidly near its maximum values (90° and 270°). Thus the change in value between 0° and 15° is much smaller than that between 75° and 90°. So with the loop aerial the difference between the strength of signal heard in the telephones when the aerial lies in the path of the wave and when it lies inclined at a small angle (e.g., 15°) to it is very slight. This difference in signal strength is extremely difficult to detect in an aircraft, owing to engine noises. On the other hand, when the aerial lies nearly at right angles to the wave direction, the signals are weaker, but the rate of change of signal strength is much more marked. Hence, the apparatus is more sensitive near its minimum position (that is, at right angles to the wave) than in its maximum position.

**2. The Bellini-Tosi system**

(i) Two large loop aerials are set up at right angles to one another, usually oriented with their planes N.–S. and E.–W. respectively. The aerials are connected to a receiver and amplifier through a *goniometer*, which consists of two coupling coils, each connected to one of the loops and set at right angles to one another, and a *search coil* which can be rotated in azimuth. The search coil is rotated by hand to such a position that the received signal is either at maximum strength or at zero (or minimum) strength. The latter is a more accurate method, but is more liable to jamming. The direction of the search coil, as indicated by a pointer moving over a dial, corresponds to the direction from which the W/T wave has arrived, or the reciprocal of that direction. A device is therefore incorporated to determine the "*sense*" of the incoming wave.

(ii) Wireless waves, as already stated, travel over the earth's surface along arcs of great circles. In addition, they pass upwards into the atmosphere, and are reflected by the *Heaviside layer*, which is thought to be a layer of air at a height of several miles above the earth's surface which has become ionised and is therefore electrically conductive.

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A conductor will reflect wireless waves, and therefore they travel back to the earth's surface and may be picked up by the horizontal portions of the loop aerials, causing errors in the goniometer readings. This effect is particularly noticeable at night, when the action of the Heaviside layer is at a maximum, and is consequently known as *night error*. The errors may be considerable.

(iii) Night error has been largely overcome by the use of the Adcock aerial system, in which the loops are replaced by U-shaped aerials, the horizontal portions of which are screened by means of earthed metallic tubes. Occasional small errors of about 2 to 3 degrees may be found, but these can be measured and allowed for.

(iv) The above systems are employed to obtain the bearing from the D.F. station of an aircraft equipped with a transmitter. In great Britain there are at present three such stations, at Andover, Mount Batten and Bircham Newton, and an aircraft can obtain on request its bearing from any one of them, or can be given its position by means of three simultaneous bearings. The method involves an extensive ground organisation. One of the three W/T stations (Andover) is the control station : this is connected with the other two by wireless employing a special wave-length. The aircraft calls up the control station according to the procedure laid down. Then, while the aircraft transmits, all three stations obtain bearings of the aircraft and the other two transmit the bearings obtained to the control station. There the operator lays down the three bearings, obtains a fix which gives the position of the aircraft at the time of the transmission, and calls up the aircraft and informs it of the position thus obtained. The total time taken need not exceed two minutes.

(v) The advantages of this method are considerable. The normal receiving and transmitting sets in the aircraft are all that is required : no special apparatus need be carried. No calculations need be undertaken in the air, but are carried out by skilled operators on the ground. The chief disadvantages are that the aircraft must disclose its position and that only one aircraft can be served at the same time.

### 3. The rotating beacon method

(i) At the beacon station an apparatus, which is, in effect, a loop aerial, is caused to rotate at a fixed and absolutely uniform rate. The beacon transmits W/T waves which may be received by an observer using an ordinary W/T receiving set, tuned to the wave-length used by the beacon station. As the apparatus revolves, the observer detects a sound which



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increases and decreases in strength in a similar way to that described in para. 1 of this chapter, the minimum signal being heard when the loop is at right angles to the line between the observer and the beacon. The difficulty of detecting the exact maximum position has already been mentioned, and this applies to the rotating beacon method. The moment when the zero or minimum sound passes the observer can, however, be detected with considerable accuracy. If, then, some special signal is transmitted at the exact instant at which the zero signal is directed towards true north, the observer can measure the interval of time between that instant and the instant at which the zero signal reaches him, and, knowing the rate of rotation of the beacon, can express this interval of time in angular measure. For example, suppose that the beacon revolves at a rate of 360° per minute and that the time interval observed is 8 seconds. Then, since the beacon revolves through 6° per second, the bearing of the observer from the beacon is 48°, and the bearing of the beacon from the observer 228°.

(ii) Since two minimum signals reach the observer during each revolution of the beacon, any bearing obtained may be the reciprocal of the correct bearing. Normally, however, an observer will not be in doubt as to whether he is, for example, east or west of the beacon station. If two or more successive bearings are obtained, there can be no doubt. For example, if an aircraft is flying north and the bearings increase in magnitude, it must be to the west of the beacon; if the bearings are decreasing, it must be to the east.

(iii) If an observer were due north or south of a beacon, he would not be able to hear the north signal. To avoid this difficulty, the beacon stations transmit two different letter signals, one at north (True) and the other at east (True). If the east signal is used, 90° must be added to the bearing obtained.

(iv) In practice it is found that an interval elapses between the instant when the signal dies away to silence and the instant when it becomes audible again. The mean of the two times must therefore be taken. Thus, suppose that the signal dies away fourteen seconds after the north signal and becomes audible four seconds later, the time would be taken as sixteen seconds, giving a bearing of 96° T.

(v) There are at present two rotating beacon stations in Great Britain, at Orfordness and Tangmere. Both transmit on the same wave-length, but the times of transmission are arranged so that one is transmitting while the other is silent. Each station has an identification signal and characteristic

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north and east signals. The cycle of transmission begins when the loop is north and south, the minimum signals being to the east and west, and for the first minute the call-sign of the station is sent out. North and east signals consist of a letter followed by two dots and a continuous dash, the beginning of the dash indicating the instant when the minimum

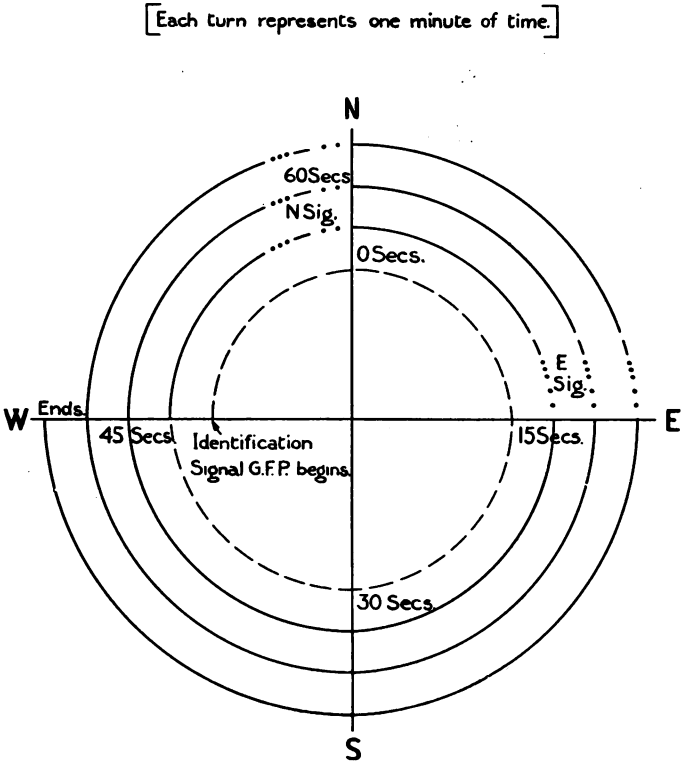


FIG. 103.—Rotating beacon—diagram of signals.

signal is north or east. Each beacon transmits for a period of four minutes every 12 minutes. During the first minute, the beacon transmits its identification signal, which is followed by the transmission of a continuous dash for three minutes, interrupted by the N. and E. signals. Fig. 103 shows in diagrammatic form the signals emitted by the Orfordness beacon.



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Details of the existing rotating beacons are as follows :—

| Name of Beacon Station. | Latitude and Longitude. | Identification Signal. | Frequency and Wave-length. | North Signal. | East Signal. | Hours of Transmission. |
|---|---|---|---|---|---|---|
| ORFORDNESS .. | 52° 05′ N.<br>01° 34′ E. | GFP | 288·5 kc/s<br>1,040 metres | V | B | Every 12 mins. commencing at 08, 20, 32, etc., minutes past the hour. |
| TANGMERE .. | 50° 51′ N.<br>00° 42′ W. | GFT | 288·5 kc/s<br>1,040 metres | G | W | Every 12 mins. commencing at 00, 12, 24, etc., minutes past the hour. |



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(vi) The advantages of the rotating beacon are that no special apparatus is needed in the aircraft, apart from an ordinary receiving set and a stop-watch, and the aircraft does not betray its position by transmitting. Any number of aircraft can make use of the beacons at the same time. The system is free from errors during the day and night errors are small. The chief disadvantages are that the size and hence the transmission range of the rotating aerial is limited from mechanical considerations, and that the transmissions can be very easily jammed.

**4. The rotatable loop method**

(i) A loop aerial consisting of many turns of wire on a rotatable frame is mounted in the aircraft and connected to a receiving set. The receiver is tuned to any transmitting W/T station, and the loop rotated until the minimum signal position is reached. A pointer coupled to the loop then indicates on a scale the bearing of the W/T station relative to the aircraft's head.

(ii) In aircraft, owing to the large amount of noise and vibration, it is very difficult to determine the exact minimum position. A modification of this method is to use a second aerial, permanently coupled to the receiver. The rotatable loop is connected to this by a change-over switch. The operator, by moving the change-over switch, can arrange that a current in the loop shall either add to the current in the second aerial or decrease it. The bearing of a station is found by rotating the loop until no alteration of signal strength is caused by moving the change-over switch. The bearing obtained may be either the required bearing or its reciprocal (*see* para. 3 (ii) of this chapter).

(iii) Before a bearing can be used, it must be corrected for *quadrantal error*. This error exists in all aircraft, being due to metal in the structure. The metal in an aircraft may be considered as having the effect of two coils at right angles, one lying in the fore-and-aft line and the other athwartships. The effect varies according to the direction of the incoming wave relative to the aircraft. The errors cannot conveniently be corrected; they are, instead, recorded and allowed for. In appendix XIII an example is given of the method of constructing a quadrantal error correction curve.

(iv) The corrected scale reading of the bearing obtained is relative to the aircraft's head and not to the meridian, i.e., is expressed as a " green " or " red " bearing (*see* Fig. 2). To obtain the true bearing of the W/T station, add corrected green bearings to and subtract corrected red bearings from

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the true course of the aircraft. (In the latter case it may be necessary to add 360° to the course before making the subtraction.)

*Example.*—A bearing is taken of a W/T station known to be approximately west of the aircraft. The scale reading is 045° G. The course of the aircraft is 070° by compass at the moment of taking the bearing. It is evident from the position of the W/T station that the scale reading cannot be 045° G., and the amended reading of 135° R. is therefore taken (*see* Fig. 104). The deviation of the compass is 2° E. and the variation 12° W. The quadrantal error correction to the bearing of 135° R. is taken from the correction curve in Fig. 124, and the true bearing is worked out as follows :—

| | | | |
|---|---|---|---|
| Scale reading given .. | 045° G. | Compass course .. | 070° |
| Amended scale reading .. | 135° R. | Deviation .. | ..+002°(E.) |
| Q.E. correction (on 135° R.) | —008° | Mag. course .. | .. 072° |
| Corrected scale reading .. | 127° R. | Variation .. | .. 012°(W.) |
| | | True course .. | .. 060° |
| | | (add) .. | .. 360° |
| | | | 420° |
| | | Scale reading .. | 127° R. |
| | | True bearing of station | 293° |

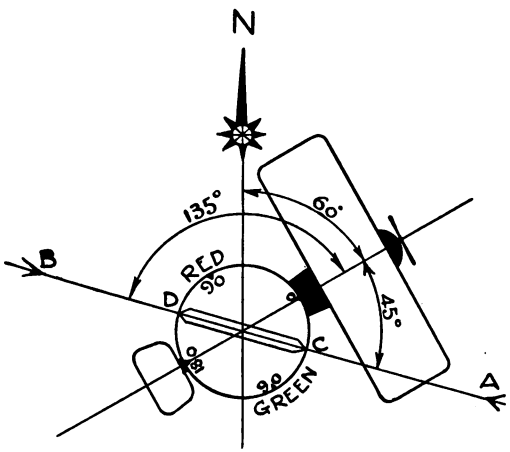


FIG. 104.—Position line by D.F. W/T.

(v) The necessity for making allowance for quadrantal error is a serious disadvantage of this method. Also, it is not free from night errors. Its great advantages are that it may be used on any recognised W/T station and that the results obtained may be checked by taking frequent check bearings.

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**5. The fixed or wing coil method**

(i) Two coils are fixed in the aircraft in the vertical plane at right angles to each other, as shown in Fig. 105. The main coil lies fore and aft, and the auxiliary coil, which either contains more turns or is larger than the main coil, is athwartships. These coils are connected through suitable apparatus to telephones worn by the pilot. The secondary coil may be replaced by a trailing aerial.

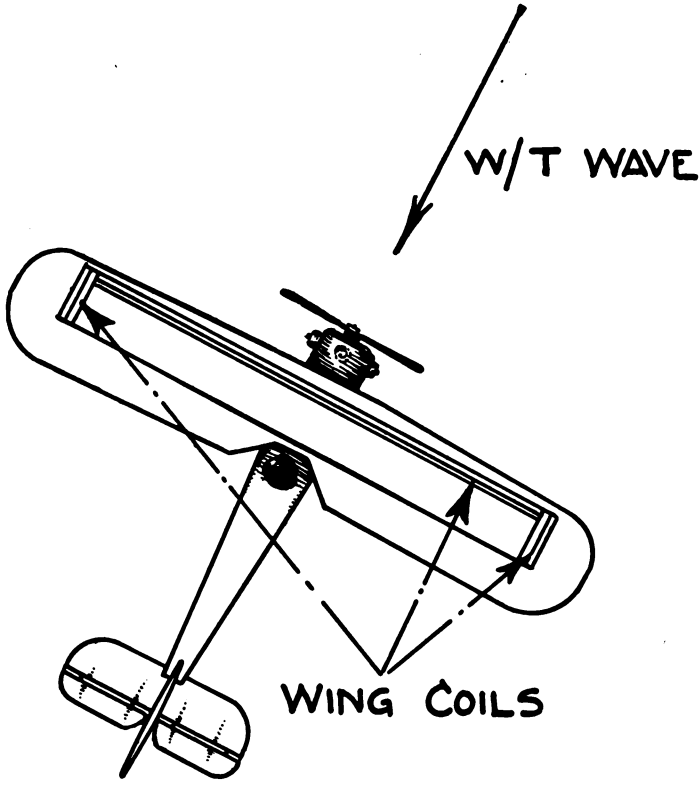


FIG. 105.—Wing coils.

(ii) The procedure is for the pilot to tune the receiver to any recognisable W/T station and to turn the aircraft until he hears maximum signals and no difference in strength is heard when the change-over switch is used. The pilot then reads the compass, and the compass course, when corrected for variation and deviation, gives the true bearing of the transmitting station.

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(iii) This method is not entirely free from night error, but the errors are small. The chief disadvantage is that bearings can only be obtained by changing course.

(iv) A development of this method, called the *Radio Azimuth*, consists of connecting the receiver to a sensitive voltmeter, which reads zero when the aircraft is heading directly towards or away from the transmitting station. When the aircraft is off course the pointer of the instrument will move to port or starboard of the zero position.

### 6. Route markers

These are sometimes called "*equi-signal beams.*" The system comprises two loops set at an angle to one another, usually 90 degrees. On a line midway between the planes of the two loops the signals emitted by the loops are of equal strength. It is thus only necessary for an aircraft to fly in such a way as to maintain equality of signals in order to make good a specified track. The comparison of the two signal strengths is obtained either by aural interlock or visual indication.

In the first method, one loop transmits signals composed of dots and dashes, and the other sends dots and dashes during the silent gaps of the first loop. On the line of equality a continuous signal is heard.

In the second method, a special receiver is used. Each loop transmits a continuous musical note, the notes being of different pitch, and the intensity of the signals is indicated by the relative amplitudes of vibration of a pair of reeds, each being tuned to the note transmitted by one of the loops.

### 7. The application of D.F. W/T to air navigation

(i) The chief application of D.F. W/T to air navigation is the obtaining of bearings which can be used as position lines and laid off on maps or charts used in the air. It should be remembered that on certain maps and charts the bearing cannot be laid down as obtained, but that the conversion angle must be applied (*see* chapter VI, para. 6). By means of the Bellini-Tosi system, positions may be obtained and plotted immediately as fixes.

(ii) One use of bearings obtained by means of one of the systems described in this chapter is to guide an aircraft to some known W/T station where the pilot can land or from which he can make his way to some other landing ground. This method is known as "*homing.*" In a dead calm, the pilot could proceed straight to the W/T station by maintaining a compass course equal to the bearing of the station observed

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(or the reciprocal of the bearing of the aircraft from that station), but in a wind which is not exactly ahead or astern this will not be possible. Consider Fig. 106. Suppose that when an aircraft is at A the bearing of a W/T station X is observed, and that this bearing is set on the compass. The effect of the wind would be to carry the aircraft to some position as B, and at that position a new bearing would be

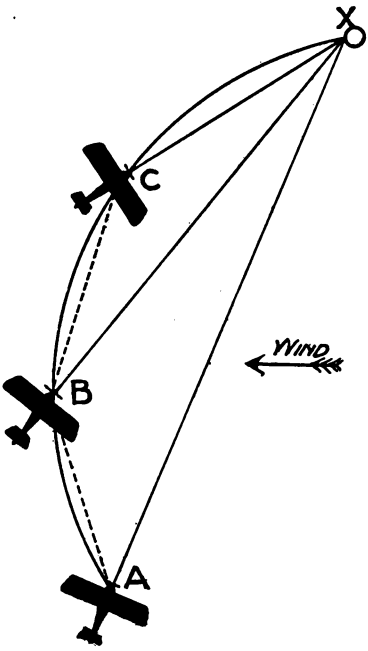


FIG. 106.—Effect of wind in " homing " by D.F. W/T.

obtained and the course would be corrected. This would be repeated at intervals, and the aircraft would follow the path ABCX, eventually reaching X approximately up-wind. In homing by D.F. W/T it is therefore necessary to observe the drift after setting course and to correct the course accordingly ; in other words to realise that the bearing obtained is the track to be made good and not the course to steer.

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## CHAPTER XVII.—METEOROLOGY

### 1. General remarks

As the element in which an aircraft moves, and by which it is supported is the air, a knowledge of the movements and behaviour of the air forms an essential part of the equipment of air pilots. The subject which treats of this branch of knowledge is called *Meteorology*. In this chapter the treatment of the subject is confined mainly to general meteorological conditions as affecting aviation in the British Isles. For further reading in Meteorology *The Weather Map* (M.O.225i) and *The Meteorological Glossary* (M.O.225ii) may be consulted. For a description of the methods of making weather observations, and the instruments in use at meteorological stations, reference should be made to *The Meteorological Observer's Handbook*. Information concerning the organisation of the meteorological services for service aviation will be found in *K.R. and A.C.I., para.* 728, and in *Air Ministry Orders*, while the organisation for civil aviation is detailed in *The Air Pilot of Great Britain and Ireland, Parts I and II*.

### 2. The weather map

(i) One of the best aids to the study of weather phenomena and the inter-relation of the different meteorological elements is the weather map. This consists of a chart on which are plotted simultaneous observations from a network of stations covering a wide area. The weather map is the basis of modern forecasting, the construction of several maps daily forming part of the routine of meteorological services.

(ii) The construction of such charts is made possible by an international organisation which has fixed the times of regular observations, the nature of the observations, the form in which they are collected, and the method of exchange of information between different countries. In Europe, the standard times of observation are 0100, 0700, 1300 and 1800 G.M.T., which is, approximately, every six hours. (In Middle East, Iraq, India and Singapore the times are slightly different.) The observations made at the different stations include pressure and its changes, temperature, humidity, wind direction and speed, weather and state of sky, height of lowest cloud and visibility. The observations are transmitted from individual observing stations to a central office in each country (the Air Ministry in the British Isles) by telephone, telegraph or wireless telegraphy, the messages being sent in a simple figure code which has also

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been agreed upon internationally. For the purpose of disseminating the information collected in this way in the countries of Europe, the Continent is divided into three main groups, the Western group, the Central group and the Russian group. As soon as each country has collected the observations from its own stations, those in the Western group communicate their observations, according to a pre-arranged time table, to Paris, while all those in the Central group forward theirs to Hamburg, and the countries of the U.S.S.R. forward their observations to Moscow. On receipt of the observations in Paris, Hamburg or Moscow, they are re-issued from high-power wireless stations so that they can be received in all parts of Europe. This arrangement ensures that, within less than two hours from the time of observation, it is possible for the various meteorological services in Europe to have received information extending from well within the Polar Circle in the north to North Africa in the south, and from the Levant in the east to the Azores and Greenland in the west. For forecasting purposes in this country information from the Atlantic is of vital importance, and the weather-reporting organisation includes a special system of reports from ships in the North Atlantic.

(iii) For the purpose of weather reports and forecasts for aviation in the British Isles the four main charts constructed from the observations made at 0100, 0700, 1300 and 1800 G.M.T. are supplemented by subsidiary charts based on observations at 1000 and 1600 G.M.T. from certain stations in this country and the neighbouring areas of the Continent. Also, during the summer months, a similar chart is prepared based on observations made at 0400 G.M.T. A new chart is thus available every three hours during the period of daylight, with the 0100 G.M.T. chart to bridge the gap during the night.

(iv) A section of a typical weather map is shown in Fig. 107. For the sake of clearness, only the wind speed and direction, temperature and weather are indicated for each station. The pressures at individual stations have not been represented, but the distribution of pressure is shown by a series of lines called *isobars*, along any one of which the *mean-sea-level* pressure at each place has the same value. The pressures as read at the observing stations are corrected and reduced to mean sea level before the weather messages are despatched, so that the pressures plotted on the charts are comparable with one another.

(v) In the weather maps in Figs. 107, 113 and 114 the wind direction is indicated by arrows flying with the wind, and the wind on the Beaufort scale (*see* Appendix XIV) is indicated by the number of feathers. The weather is indicated by the Beaufort letters, *b* representing clear sky, *bc* sky about half-clouded, *c* cloudy sky, *o* overcast sky, *r* rain, *d* drizzle, *s* snow,

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*p* showers and *jp* showers in neighbourhood of station. In the case of precipitation capital letters denote intensity: thus, *R* means heavy rain. A solidus divides actual weather from preceding conditions: thus, *c/r* means cloudy sky after rain. This method of plotting weather reports is used here for clarity of representation on a small-scale map. In actual practice at the meteorological offices in this country, all the

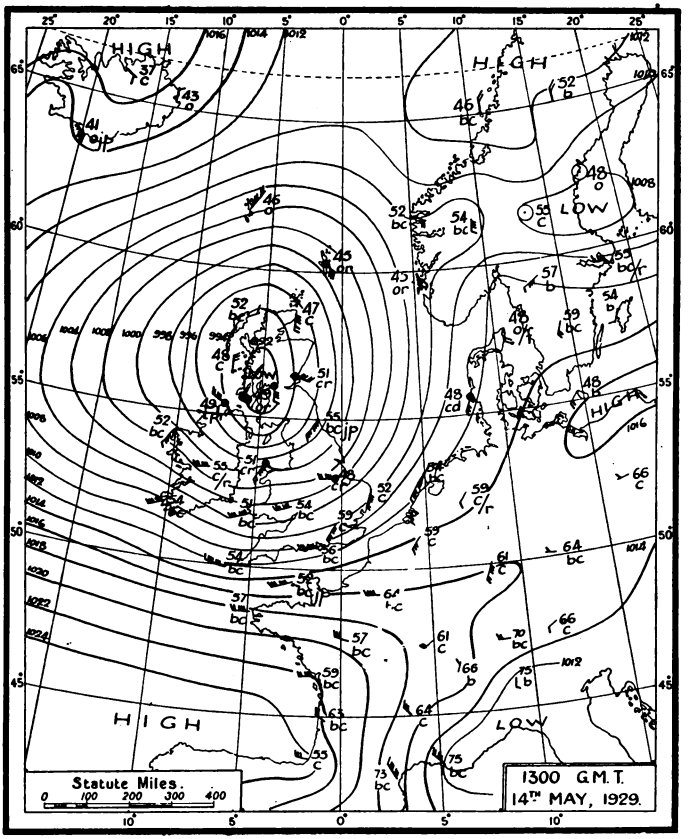


FIG. 107.—Synoptic weather chart.

weather elements observed and reported are plotted on the chart in a uniform manner, as each of these is of great importance in preparing reports and forecasts for aviation purposes.

(vi) The isobars drawn on weather maps do not run in a featureless manner over the chart, but show one or a combination of easily recognisable patterns, the arrangement of pressure distribution falling generally into areas where pressure

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is lower than in the surrounding parts, and into regions where it is higher than in the adjacent localities. The areas of comparatively low pressure are variously called *depressions*, *cyclones* or *lows*, while the regions of comparatively high pressure are called *anticyclones* or *highs*.

### 3. Pressure

(i) The pressure of the atmosphere at any point in it is due to the weight of overlying air. Pressure at the surface of the earth is usually measured by means of a mercury barometer, and for this reason it is frequently expressed in inches of mercury. A measurement of pressure so expressed really means the length of the column of mercury, the weight of which will balance that of a column of air extending from the ground to the top of the atmosphere. Pressure, however, is a force, and in meteorological work it is usual to employ a C.G.S. unit, the *millibar*, to measure it : a millibar is the pressure exerted on an area of one square centimetre by a force of 1,000 dynes. A pressure expressed as 30 inches of mercury is equivalent to 1015·9 millibars.

On weather maps isobars are drawn for intervals of 1, 2 or 4 millibars according to the scale of the chart. In the maps reproduced in this chapter the interval is one of 2 millibars.

(ii) From the definition given, it will be obvious that pressure diminishes gradually with height. The *average* rate of diminution in the lower levels is 1 millibar for every 30 feet. The *actual* rate of decrease depends, however, on the temperature of the air : the higher the temperature, the less dense is the air, and the slower will be the rate of decrease of pressure upwards ; consequently the pressure at any given height will be higher than if the air from the ground to that height were colder. Pressure also varies with time and place, the variations, which are irregular, being associated with weather changes which are due to the changes in position and intensity of high and low pressure systems.

### 4. Effect of variation of pressure and temperature on altimeter readings

(i) The effects of temperature on the variation of pressure with height, and the variation of pressure with place, have an important bearing on the readings of the altimeter.

(ii) The altimeter is a special form of aneroid barometer which expresses changes in pressure in terms of height. To graduate the altimeter it is necessary to assume an ideal atmosphere, and, in most of the altimeters in current use, the temperature of this atmosphere is taken to be 50° F. (10° C.). Since the rate of decrease of pressure with height depends on

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temperature, any variation from this standard temperature of 50° F. will produce an error in the altimeter reading. Thus, if the altimeter of an aircraft in flight reads 5,000 feet, the true height will be 5,000 feet only if the temperature of the air from the ground to the aeroplane is 50° F., but if the mean air temperature is below 50° F., say 30° F., the true height will be less than 5,000 feet, because the air below the altimeter is denser than the standard atmosphere. An approximate rule for allowing for this effect of temperature is to subtract 1 per cent. of the height for each 5 degrees Fahrenheit by which the mean temperature from the aircraft to the ground is below 50°, and vice versa. In the example cited the true height would be less than 5,000 feet by 1 per cent. of $5{,}000 \times \frac{(50-30)}{5}$ or 200 feet.

(iii) The effect of the variation of sea-level pressure from place to place may be important in a long cross-country flight. Consider, for example, the case of a flight from Leuchars to Gosport on the day to which the weather chart in Fig. 107 applied. The sea-level pressure at Leuchars was 994 mb., and if the altimeter was set to read zero at the start of the flight, it would have read zero when near Gosport at the height at which the pressure was also 994 mb. But the sea-level pressure at Gosport was 1,010 mb., a difference of 16 millibars, and since pressure decreases at the rate of 1 millibar in 30 feet, the pressure would have been 994 mb. at 30 × 16 or 480 feet above sea-level. In other words, the altimeter at Gosport would have underestimated the true height by 480 feet. Similarly, in flying from high to low pressure an altimeter would register in excess of the true height. The latter case is the more important in practice, particularly when flying in bad weather on a day when there is a large horizontal variation of pressure. From considerations dealt with in para. 7, it will be seen that if a pilot is flying with a *strong wind* on his *port* beam he is flying into an area where pressure is considerably lower than at his starting point, and his altimeter is overestimating, perhaps dangerously.

In the example cited it was assumed that the pressure did not change during flight. Actually there would usually be a slight change from the conditions given by the latest weather chart, but allowance can be made for this, and a close estimate of the pressure at the aerodrome of destination at the time of arrival obtained from the charts.

### 5. Temperature

(i) The variation of temperature over the earth's surface is of considerable importance in meteorology since it is the key to many of the physical processes which form part of the

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atmospheric machinery. The main source of atmospheric heat is not the direct rays of the sun, but the earth's surface, which absorbs *radiation* received from the sun, the energy absorbed being converted into *heat.* The air in contact with the heated earth becomes itself heated by *conduction,* and the heat thus acquired is transferred from lower to higher levels mainly by the process of *convection,* or the actual ascent of air which has been warmed by contact with the ground. Temperature, therefore, diminishes normally with height above the ground, at least for the first 7 miles or so. The average rate of decrease or *lapse rate* in this layer of air is 3° F. per 1,000 feet, although the actual lapse rate on a particular day may differ considerably from the average value, particularly in the lower layers near the ground. In certain conditions, temperature may actually increase with increasing height forming an *inversion.* Near the ground an inversion is most readily produced during a clear night in winter when the earth's surface radiates its heat to the sky and becomes cooled, thus cooling the air in contact with it. This air becomes colder, therefore, than the air at some distance above the earth, and an inversion is established.

(ii) If a mass of air becomes warmer than the surrounding air, it expands and, becoming lighter than its environment, tends to rise. In rising it becomes cooled by expansion owing to the fact that pressure diminishes with increasing height. If there is no gain or loss of heat from outside the mass of air, the change is said to be *adiabatic* and the rate of fall of temperature in these conditions for dry air is 5·4° F. per 1,000 feet. This is called the *dry adiabatic lapse rate.* If the lapse rate in the surrounding air is greater than the dry adiabatic lapse rate the air will go on rising, for at any height it will be warmer, and therefore lighter, than its environment. The atmosphere is then said to be *unstable.* If, on the other hand, the lapse rate is less than the dry adiabatic lapse rate, the air instead of rising will tend to fall back, for it will be colder, and therefore heavier, than its environment ; the atmosphere is then said to be *stable.* The smaller the lapse rate the more stable will be the air. An inversion is, thus, a very stable condition.

### 6. Wind

(i) Wind is the movement of air necessary to balance two forces acting upon the air : namely, horizontal changes of pressure, and the rotating motion of the earth.

(ii) An examination of the weather chart in Fig. 107 will show that the wind arrows tend to follow the run of the isobars, but that they are inclined towards the side of lower pressure. Further, the closer the isobars are together, the stronger is the wind. The relation between the direction of the

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wind and the distribution of pressure is expressed by Buys Ballot's law which states that if you stand with your back to the wind in the northern hemisphere the lower pressure is on your left. In the southern hemisphere the reverse will hold.

(iii) At a certain height above the ground it is found from actual measurement that the wind blows along the isobars and that the wind speed is proportional to the pressure gradient, that is, the rate of change of pressure horizontally in a direction perpendicular to the isobars. In practice, the wind calculated from the pressure gradient agrees with the observed wind at a height of about 1,500 feet. Thus, if from a weather chart the direction of the isobars and the pressure gradient at a certain point are measured, a close approximation to the direction and speed of the wind at 1,500 feet is obtained. In practice, a scale is used which, when placed on the map across the isobars gives directly the speed of the wind in miles per hour at 1,500 feet. The mean-sea-level pressure isobars therefore give the lines of flow of the air at 1,500 feet, and are of great assistance in allowing for wind in air navigation.

(iv) The deviation of the surface wind from the direction of the isobars is due to friction between the lower layer of air and the earth's surface, which acts as a retarding force reducing the wind speed. The effect of the friction is to produce eddies which result in *gustiness* in the wind near the ground. The existence of these eddies, or *turbulence*, is made visible by the smoke from a chimney. If there were no friction, and consequently no turbulence, the wind would blow as a steady current with uniform speed and direction, whereas actually it blows in a succession of gusts and lulls of the order of a fraction of a minute. The gustiness which occurs in the wind is evident from Fig. 108, which is a reproduction of a trace from a recording anemometer, the upper trace giving the wind speed during the course of a day and the lower trace the direction. Turbulence varies with the nature of the surface over which the wind is blowing, increases as the wind speed increases and decreases with height. It is also affected by temperature and extends to a greater height in summer than in winter, and also to a greater height in the day than at night.

### 7. Variation of wind with height

(i) It will be evident from the preceding paragraph that there must be an increase in wind speed from the surface, where the effect of friction is greatest, up to a height of 1,500 feet where the wind current is relatively undisturbed, and also that the wind direction must at the same time *veer*, that is, change in a clockwise direction. While this is usually true of all winds, no general rule can be laid down for the increase



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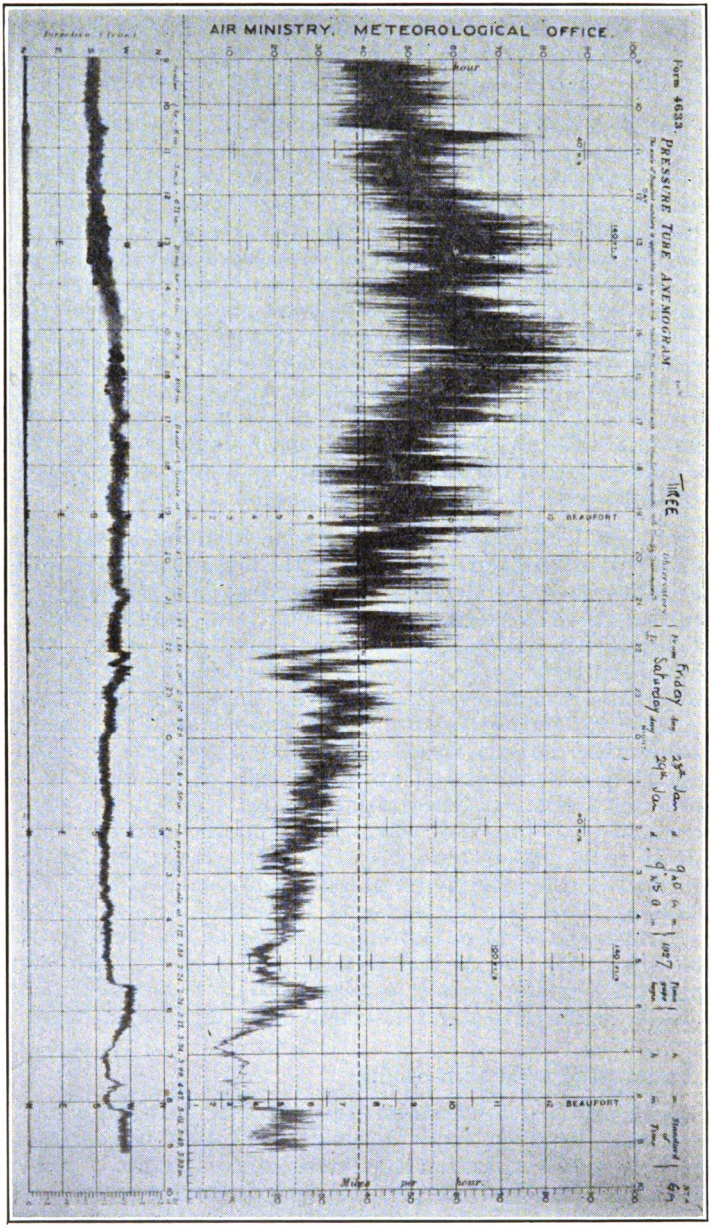


FIG. 108.—Record from Dine's pressure tube anemometer.

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of wind with height, for it depends on the actual direction and speed of the wind, the time of day, the season of the year and local topography.

(ii) Above the 1,500 feet level, the change in wind speed and direction with height varies with the direction of the wind. Thus, winds from a westerly point usually continue to increase in speed and veer with increasing height. Easterly winds, on the other hand, tend to fall off with height, and above 3,000 feet are often replaced by winds from a westerly point. At greater heights, the wind is controlled partly by the horizontal distribution of temperature. Knowing the sea-level distribution of pressure and the temperatures at different heights, it is possible to compute the pressure distribution at various levels and from the pressure distribution the winds at those levels can be obtained with fair accuracy. It will be clear from paragraph 3 that the pressure at any level depends on the temperature in the intervening layers, so that if there is a large difference of temperature horizontally the wind distribution at high levels must be affected appreciably. The effect of such a variation of temperature is to superpose on the general wind distribution a wind blowing round the area of lower temperature in the same way that the wind in the lower levels circulates round an area of low pressure. For example, if temperatures are uniformly high over the northern Atlantic and uniformly low over the Continent, winds at high levels over England will tend to be northerly, although the surface wind may be southerly.

(iii) The irregularity in the variation of wind with height makes the question of obtaining accurate data about the winds at different heights one of importance in air navigation. At meteorological stations the winds are measured by means of small rubber balloons filled with hydrogen to rise at a predetermined rate. The motion is observed by means of a specially constructed theodolite and readings of the altitude and azimuth are taken every minute. Assuming the rate of rise of the balloon, it is then possible to calculate by a slide rule the speed and direction of the wind in consecutive layers. By attaching a long tail to the balloon, and observing its length on a graticule in the eye-piece of the theodolite, the necessity for assuming the rate of ascent of the balloon is avoided. The most accurate method is to use two theodolites at the end of a measured base line, but this method is less convenient than the single theodolite method as it requires more personnel and a longer time for working up the results. When balloon observations are not possible owing to weather conditions, useful information can be obtained from the movements of clouds and from synoptic weather charts.



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### 8. Diurnal variation of wind

The turbulence in the lower layers of air is responsible for a diurnal change in the wind speed and direction in these layers. During the day, turbulence is active and the lower layers of the atmosphere become well mixed. The wind at, say, 1,000 feet gives up some of its momentum to the wind near the ground which, consequently, increases in speed reaching a maximum usually in the early afternoon. At the same time the direction of the wind near the ground tends to veer towards the direction of the wind at 1,000 feet. At night turbulence almost ceases, and the wind near the ground backs and lulls. At 1,000 feet the reverse takes place, the wind backing and decreasing during the day and reaching its maximum speed at night. A height of 1,000 feet has been taken as an example, but the actual upper limit of the height at which these changes take place depends on the strength of the wind and the season of the year. In general, it may be stated that the veer and increase of wind in the first 1,500 feet, which was noted in para.7, is more marked at night than in the middle of the day. The changes outlined may be completely masked, however, by temporary variations in weather conditions. They would be most in evidence, normally, on a fine, relatively quiet, day in summer, and much less marked in winter.

### 9. Local winds independent of general pressure distribution

There are certain important exceptions to the general rule stated in para. 6 regarding the relation between wind direction and the general pressure distribution. Of these the following may be noted:—

(i) *Anabatic winds.*—On a hot day the air in valleys is warmed and, owing to its decreased density, tends to rise, flowing up the valley and up the slopes of hills. Such a wind is called *Anabatic.*

(ii) *Katabatic winds.*—On a clear night the ground becomes cooled by radiation to the sky and the air in contact with the ground consequently becomes cooled. In undulating country the air on the surface of a hill, being colder than the air at some distance from the surface, tends to flow down the slope under gravity causing a local wind. The direction of this wind, which is called *Katabatic,* is determined by the slope of the hill and may bear no relation to the pressure distribution. Under favourable conditions the speed of the wind may exceed that of the gradient wind, especially if the pressure gradient tends to augment the influence of the hill.

(iii) *Land and sea breezes.*—In summer during the day the land surface near the coast becomes much hotter

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than the surface of the sea. The air over the land consequently becomes warmed and expands and at some distance above the surface the pressure is therefore higher than that at the same level over the neighbouring sea. Consequently air flows at this higher level from land to sea until the pressure at the surface over the sea becomes higher than at the surface over the land. A return surface wind therefore blows from sea to land and this circulation continues throughout the day. This wind is called a *sea breeze*. Sea breezes are usually less than 500 feet in vertical extent, but may extend occasionally to 1,000 feet or even over. As in the case of katabatic winds, they may bear no relation to the pressure distribution. At night conditions are reversed, the land surface becoming colder than the sea. The surface wind then tends to blow from land to sea, and in quiet weather persists till the morning.

**10. Vertical currents—Bumpiness**

(i) The wind flow over the earth's surface is not entirely horizontal. There are various causes present which, acting either singly or in conjunction tend to produce a vertical component in the motion of the air. Apart from the gustiness referred to in para. 6, ascending and descending currents in the atmosphere constitute the chief cause of bumpiness in flying.

(ii) *Dynamic up-currents.*—The most obvious way in which deviation from the regular horizontal wind flow may be produced is by means of an obstruction such as a ridge of hills. If the latter is at right angles to the wind direction the air must, of necessity, pass over the summit, producing an upward current on the windward side and a downward current on the lee side. In such a case the vertical motion extends to an average height above the summit equal, approximately, to four times the height of the ridge. The actual height to which the disturbance extends depends, however, on the temperature lapse rate, being greater when the latter is large. If, on the other hand, a temperature inversion exists at some height above the hill no vertical motion is possible above the level of the inversion and no bumps are experienced when flying over the hill above this level. These conditions occur most frequently in winter in the relatively quiet conditions associated with an anticyclone (*see* para. 19).

In the case of a hill with steep slopes, there is a tendency for stationary eddies to be formed on both the windward and leeward sides, the wind blowing down the hill near the bottom of the slope on the windward side and up the hill on the leeward side (*see* fig. 109 (*a*)). Between the main upward or

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downward current and the return current close to the hill, a shadow area, or region of dead air will be found to exist. Such eddies persist so long as the lapse rate is less than the dry adiabatic and the wind speed is less than about 20 m.p.h. If the lapse rate or wind speed exceeds these values, the wind flow over the hill becomes generally turbulent and the more definite larger eddies are difficult to distinguish.

The wind flow over a cliff with a steep face is more turbulent than in the case of a hill. Fig. 109 (*b*) and (*c*) illustrates the types of disturbance produced when the cliff faces to windward and to leeward respectively. In the latter case the eddies may persist for a considerable distance to leeward causing dangerous flying conditions. An example of a disturbance of this kind is found in the wind currents over the Rock of Gibraltar.

(iii) *Frictional up-currents.*—In a coastal region when the wind blows from the sea up-currents are produced by surface friction. Owing to the increased friction which occurs in the transition from sea to land, the wind experiences a strong retardation or decrease in velocity. This decrease is compensated by a corresponding ascending current over the coast.

Ascending currents along the coasts, due to this cause, occur more particularly in summer with a sea breeze. Evidence of the upward current is seen in the long line of cumulus cloud (*see* para. 14) which persists along the coast line. The upward current is reinforced if there is high ground bordering the coast.

(iv) *Thermal up-currents.*—Considerable vertical currents are produced owing to the irregular heating of the earth's surface by the sun. On a fine day in summer, particularly if there is little wind, the ground rapidly becomes heated, causing the air at lower levels to approach the unstable adiabatic state. Streams of air then flow upwards from the ground and, if the air is sufficiently moist, a cumulus cloud forms at the top of each rising column. As the cloud grows, a powerful circulation develops within it, drawing in air from lower levels. A sky covered with such cloud produces alternating ascending and descending currents with correspondingly disturbed flying conditions.

The extent to which the ground becomes heated depends on the nature of the surface. Thus, thermal up-currents are more pronounced over some kinds of terrain than over others. Bare rocky or sandy soil becomes heated much more readily than land covered with grass or vegetation. Upward currents are experienced on a hot day over such areas which contrast with their surroundings while downward currents are found over lakes, rivers and forests.

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Another example of thermal up-currents is seen in the case of a cold current of polar origin which, having reached England by flowing southward over warmer water, has become unstable. In such conditions squally winds accompanied by severe bumps may be experienced. These conditions occur most frequently in spring when the ground is becoming warmer and the upper air is still relatively cold.

(v) *Frontal up-currents.*—The vertical currents considered hitherto have been the effect, either directly or indirectly, of the topography of the earth's surface. The most powerful up-currents experienced, however, are due to purely meteorological causes which are, in the main, independent of the nature of the surface below. These up-currents are due to the interaction of air masses which, being of different thermal structure, produce disturbed conditions along the boundaries where they meet. The most important type of disturbance is the cold front of a depression, along which the cold northerly or north-westerly winds of polar origin in the rear of the depression undercut the warmer south-westerly winds on the southern side (*see* para. 18). The most intense upward currents occur in line-squalls and more particularly in thunderstorms which are described in paras. 21 and 22.

## 11. Humidity

(i) The air contains a certain quantity of water vapour, the amount being subject to wide variation with both time and place. The maximum amount of water vapour which the air can take up depends on its temperature ; the warmer it is the more water vapour it can hold. When the air contains as much water vapour as it can hold it is said to be *saturated*. Any mass of air containing water vapour can therefore be cooled down until it is saturated. The temperature to which unsaturated air has to be reduced before it becomes saturated is termed the *dew-point*. Any further cooling results in some of the water vapour being condensed into water drops. The actual amount of water vapour which a given sample of air contains is called the *absolute humidity*. It is more usual, however, to express the amount as a percentage of the amount which the air would contain if saturated at the same temperature. This percentage is termed the *relative humidity*.

(ii) Air which contains water vapour but which is unsaturated behaves under pressure changes as if it were dry air ; on rising it cools at the rate of 5·4° F. per 1,000 feet. When saturated air rises, however, the expansion and cooling produce condensation which is accompanied by the liberation of heat. The result of this is to practically halve the rate of

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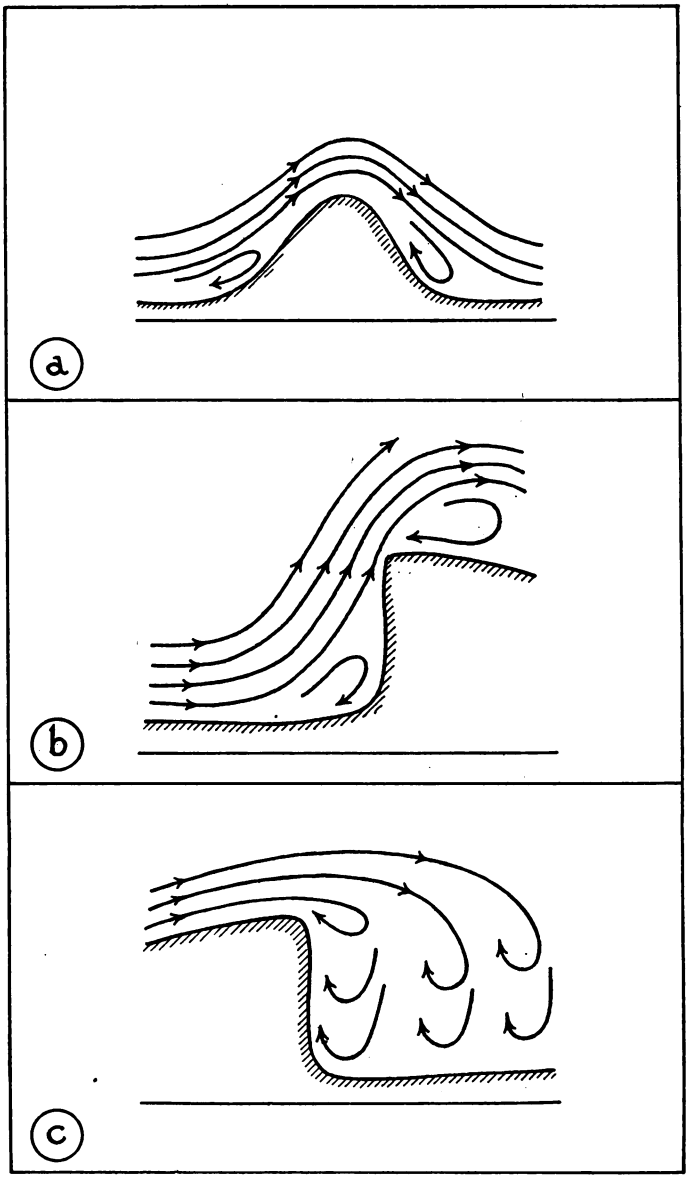


FIG. 109.—(*a*) Air flow over hill with steep slopes.
(*b*) Air flow over cliff facing to windward.
(*c*) Air flow over cliff facing to leeward.

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cooling which unsaturated air undergoes on rising. The rate for ascending saturated air, which depends on the temperature of the air, is only 2·6° F. per 1,000 feet at 50° F. This is called the *saturated adiabatic lapse rate.*

## 12. Fog

(i) *Fog* is probably the most important meteorological element from the point of view of aviation in these latitudes. It may be caused by the condensation of water vapour in the surface layers of the atmosphere or it may be due to smoke or dust held in suspension in the air, or a combination of water vapour and smoke. It is usual to limit the term " fog " to a condition of atmospheric obscurity in which objects at a distance of one kilometre (approximately 1,000 yards) are not visible. When the visibility exceeds one kilometre, but is less than two kilometres, the obscuration is called " *mist* " or " *haze* " according to whether it is produced by condensed water particles or by solid matter such as dust or smoke. Condensation of water vapour in the surface layers of the atmosphere is brought about by the cooling of the air below its dew point. The cooling may be due to the cooling of the surface of the ground which is communicated to the air above it, by the drift of air over a surface which is colder than itself, or, more rarely, by the mixing of two currents of air of different temperatures and humidities. In the first two cases an inversion is formed in the lower layers of air, which effectively prevents the air from rising. The turbulent mixing of the moist air within the layer of the inversion causes condensation. For the effective formation of fog the wind must be light in order to allow the air near the ground to become sufficiently cooled ; also there must be sufficient moisture in the air for the cooling to produce condensation. The wetness of the ground therefore has a bearing on the likelihood of occurrence of fog.

(ii) Fogs over land occur chiefly in autumn and winter. They are formed most frequently on calm, clear nights. They reach their maximum intensity, normally, in the early morning, from one to two hours after sunrise, and usually disperse before mid-day. In winter, however, they may cover a wide area and persist for some days. Fogs at sea, on the other hand, are characteristic of spring and summer, and are usually formed by the passage of a current of air from a large land mass, or from tropical or sub-tropical regions, over the sea which, at this season, is relatively cold. Over the English Channel they usually occur with warm south-west winds. In undulating country fog may occur at all seasons due to the drifting of low cloud over the high ground. High ground near the sea suffers the most in this respect.

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(iii) Near large towns and industrial areas where there is a continuous output of smoke from factory chimneys, etc., smoke fogs are frequent. Their formation is most favoured by similar conditions to those which give rise to water fogs, since an inversion and a light wind prevent the smoke from dispersing quickly either vertically or horizontally. Such fogs may be carried a considerable distance to leeward of the source of pollution. The worst fog occurs when conditions are also favourable for condensation and a mixture of the two kinds of fog produces considerable obscurity.

(iv) The height to which an ordinary fog extends varies considerably. It is usually less than 1,000 feet and frequently less than 500 feet. In certain conditions a fog has no clearly defined upper boundary but merges into cloud which may extend to a considerable height.

(v) In the case of a fog formed at an inland station at night by radiation cooling, it is frequently possible to make an accurate forecast of the probability of fog based entirely on local readings of wet and dry bulb thermometers, which form a convenient method of measuring the humidity of the air. The thermometers should be exposed in a standard Stevenson Screen, and should be sufficiently remote from buildings or other obstacles to prevent the latter from influencing the readings. The following rules are used in conjunction with the diagram in Fig. 110 which connects the readings of the dry bulb thermometer at 2000 G.M.T. with the difference between the readings of the dry and wet bulbs. The diagram should apply with little modification to any inland aerodrome in a flat situation in England:

(*a*) The diagram can only be used if the sky is clear or not more than half-clouded.

(*b*) If the wind at 2000 G.M.T. is above 8 m.p.h. at 5 feet above the ground, there is little risk of fog or mist.

(*c*) If the wind at 2000 G.M.T. is calm, there is considerable risk of fog or mist whatever may be the thermometer readings.

(*d*) If the wind at 2000 G.M.T. is less than 8 m.p.h. the risk of fog is considerable if the temperature readings give in the diagram a point which comes below the sloping line.

### 13. Visibility

*Visibility* is defined by the maximum distance at which an object can be seen and the clearness with which its details can be discerned. It is measured at meteorological stations by selecting a number of well-defined objects at certain specified distances and by observing the most distant of these objects which is visible. Apart from the bad visibility

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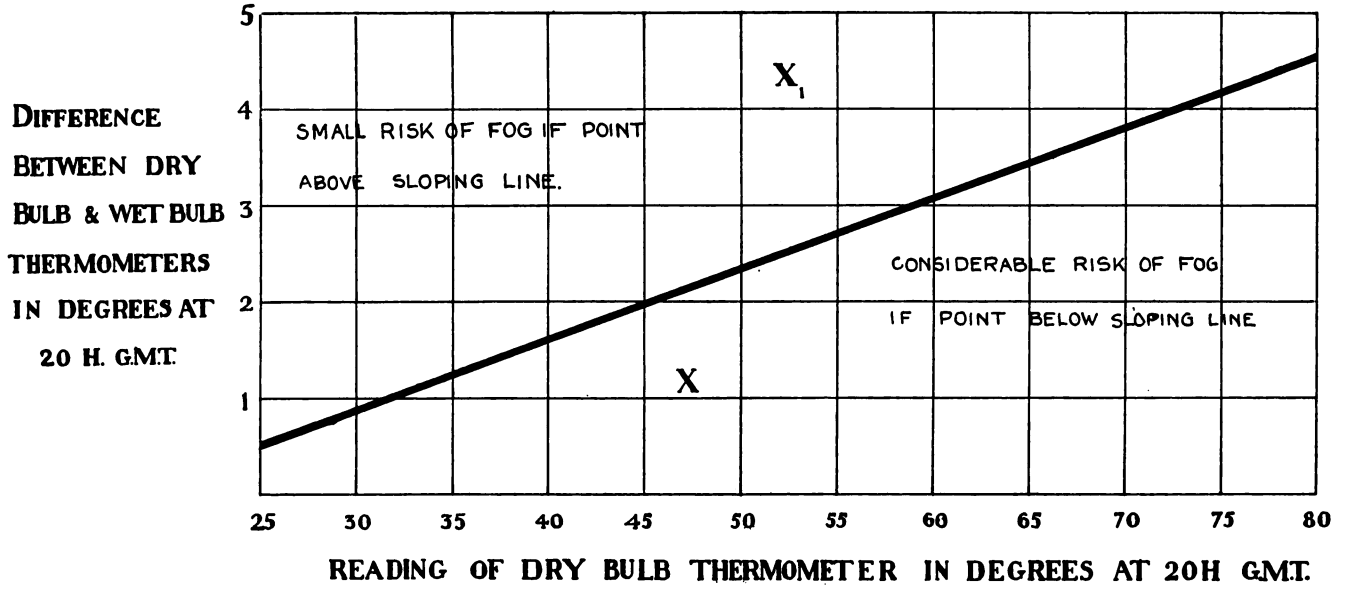
DIFFERENCE BETWEEN DRY BULB & WET BULB THERMOMETERS IN DEGREES AT 20 H. G.M.T.
5
4
3
2
1
SMALL RISK OF FOG IF POINT ABOVE SLOPING LINE.
X1
X
CONSIDERABLE RISK OF FOG IF POINT BELOW SLOPING LINE
25 30 35 40 45 50 55 60 65 70 75 80
READING OF DRY BULB THERMOMETER IN DEGREES AT 20H G.M.T.

FIG. 110.—Fog prediction diagram for England.

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associated with such phenomena as fog, heavy rain and snow, one of the most important factors in determining visibility is the position of industrial areas and large towns. The visibility in a certain area may thus vary considerably with different wind directions. In general, good visibility near the ground is associated with a high temperature lapse rate, when atmospheric pollution is carried upwards by convection, and bad visibility with a low lapse rate, especially with an inversion. At higher levels, however, visibility may be different from that near the ground. For example, on a hot day in summer convection currents may carry smoke upwards to 5,000 or 6,000 feet forming a layer of haze. Smoke haze is often carried by the upper winds to a considerable distance from the source of pollution in a gradually widening belt. Thus, in spring when east winds are relatively frequent and the lapse rate is high, thick haze from the industrial districts of Belgium and Germany may be encountered over England. Similarly north-west winds often bring thick smoke-haze from the Midlands to south-east England. In winter haze at high levels usually occurs with north-west winds which are more frequently characterised at this season by a high lapse rate than winds from other directions. Visibility is also dependent partly on optical considerations; on a hot day, the shimmer of the air over hot ground makes objects indistinct, while in the air cloud shadows and light reflected from clouds may make observation difficult.

## 14. Clouds

(i) The number of forms which clouds may take is almost infinite, but for purposes of description it is necessary to adopt some kind of classification. The system adopted is based on the observed appearance and mean height of the cloud, and is known as the International Cloud Classification. Some of the more commonly occurring cloud forms are illustrated in Fig. 111. Several forms may, of course, occur at the same time.

The following are the main cloud types :—

(*a*) *High Clouds.* (Mean height above 20,000 feet.)

1. *Cirrus* (*Ci.*).—Delicate, isolated clouds of fibrous texture in wisps or bands.

2. *Cirro-cumulus* (*Ci.-Cu.*).—Layer or band of cloud composed of small white tufts. Often arranged in groups, lines or ripples.

3. *Cirro-stratus* (*Ci.-St.*).—A thin whitish veil of cloud sometimes covering the whole sky, through which the sun or moon is visible, often with a halo.

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(*b*) *Middle Clouds.* (Mean height 7,000 to 20,000 feet.)

1. *Alto-cumulus* (*A.-Cu.*).—A layer or band of cloud composed of small globular masses arranged in groups, lines or rolls. At high levels somewhat resembles cirro-cumulus.

2. *Alto-stratus* (*A.-St.*)—Fibrous or striated veil of cloud of bluish or grey colour somewhat resembling cirro-stratus but thicker and darker than the latter.

(*c*) *Low Clouds.* (Mean height below 7,000 feet.)

1. *Strato-cumulus* (*St.-Cu.*).—A layer or bank of cloud composed of large masses showing some vertical structure and arranged in lines, rolls or waves following one or two directions.

2. *Stratus* (*St.*).—A uniform layer of cloud resembling fog but not resting on the ground.

(*Fracto-stratus* (*Fr.-St.*).—A stratus broken up into irregular, ragged fragments.)

3. *Nimbo stratus* (*Nb.-St.*).—A low, rainy layer of cloud of a dark grey colour and nearly uniform.

(*Fracto-nimbus* (*Fr. Nb.*).—Low, dark, ragged clouds associated with bad weather.)

(*d*) *Clouds with marked vertical structure.* (Mean height from 1,500 feet to Cirrus level.)

1. *Cumulus* (*Cu.*).—Flat base clouds with vertical structure and cauliflower-shaped tops.

(*Fracto-cumulus* (*Fr.-Cu.*).—Small cumulus clouds with ragged tops which continually change their form.)

2. *Cumulo nimbus* (*Cu. Nb.*).—Large towering cumulus of great depth, the upper part being composed of fibrous cloud drawn out in wisps, or sometimes in the shape of an anvil.

(ii) Clouds, like fog, are caused by the condensation of water vapour in the air when it is cooled below its dew point, but whereas fogs are formed by the cooling of air without any change of level, the cooling, in the case of cloud formation, is brought about almost invariably by the adiabatic expansion of rising air. Speaking broadly, the methods of formation of clouds may be classified as follows :—

(*a*) *By direct ascent of air.*

1. *Topography.*—Wind blowing against a range of hills or mountains is forced to rise and a long bank of cloud, more or less continuous, forms on the upper part of the mountains or above the hills. Temperature falls with increasing height throughout the cloud.

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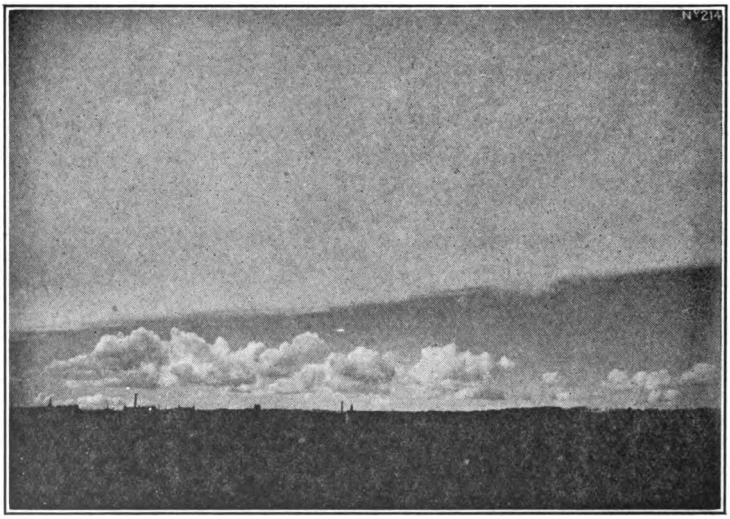
(1) Cirrus (**Ci.**). Mares' tails with tufted ends, often at about 30,000 ft.



(2) Cirro-Stratus (**Ci.-St.**) uniform sheet of very high cloud, 30,000 ft.; about 25,000 beneath is Fracto-cumulus (**Fr.-Cu.**) a string of ragged cumulus at about 6,000 ft.

FIG. 111.—CLOUD FORMS.

(Photographs selected from the collection of Mr. G. A. CLARKE of the Observatory, Aberdeen.)

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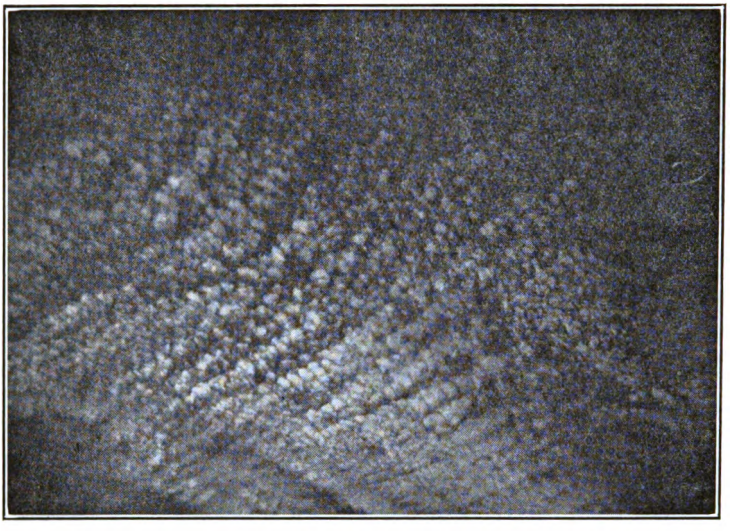
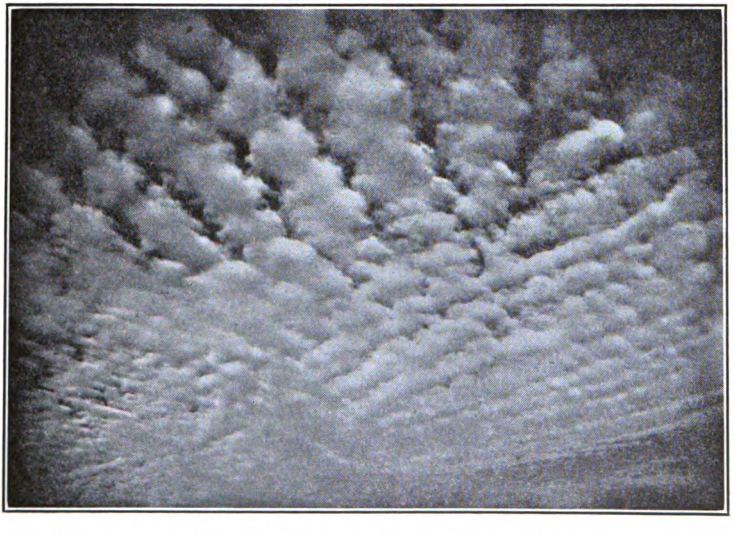


(3) Cirro-Cumulus (**Ci.-Cu.**). The Mackerel Sky. The highest form of cloudlets in waves : 20,000 to 25,000 ft.



(4) Alto-Cumulus (**A.-Cu.**). Layer of large cloudlets in waves at middle height.

FIG. 111.—CLOUD FORMS—*continued.*

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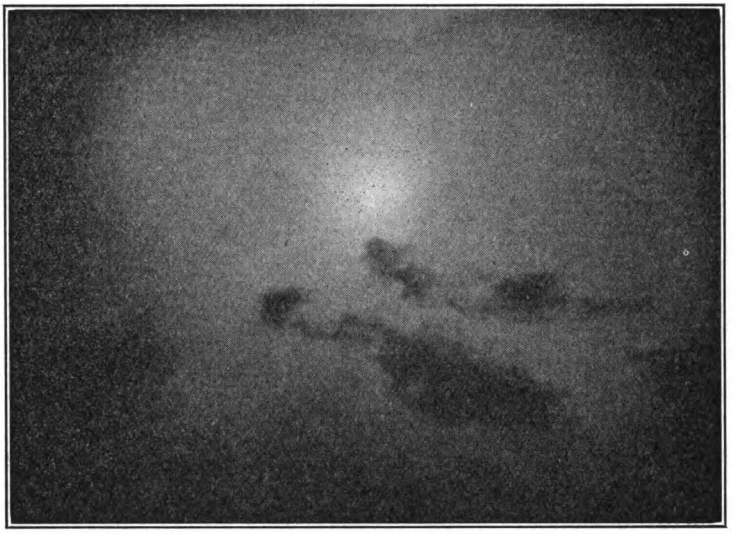

(5) Alto-Stratus (**A.-St.**). Sheet at middle height, between 10,000 and 25,000 ft.

(6) Strato-Cumulus (**St.-Cu.**). Layer of clouds in irregular order below 7,000 ft.

FIG. 111.—CLOUD FORMS—*continued*.

(Photographs selected from the collection of Mr. G. A. CLARKE of the Observatory, Aberdeen.)

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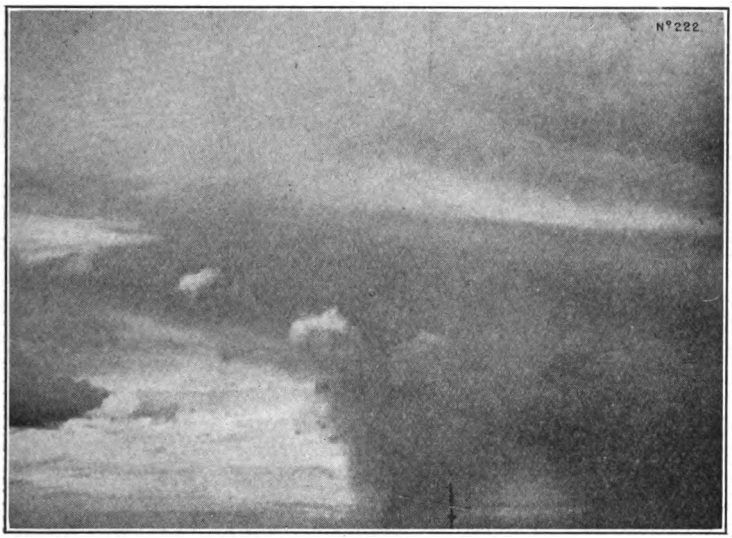


(7) Nimbus (**Nb.**). Shapeless cloud-base below 7,000 ft., rain falling.

(8) Cumulus (**Cu.**). Detached cloud with flat base at mean height 4,500 ft., and domed top at mean height 6,000 ft.

FIG. 111.—CLOUD FORMS—*continued.*

(Photographs selected from the collection of Mr. G. A. CLARKE of the Observatory, Aberdeen.)



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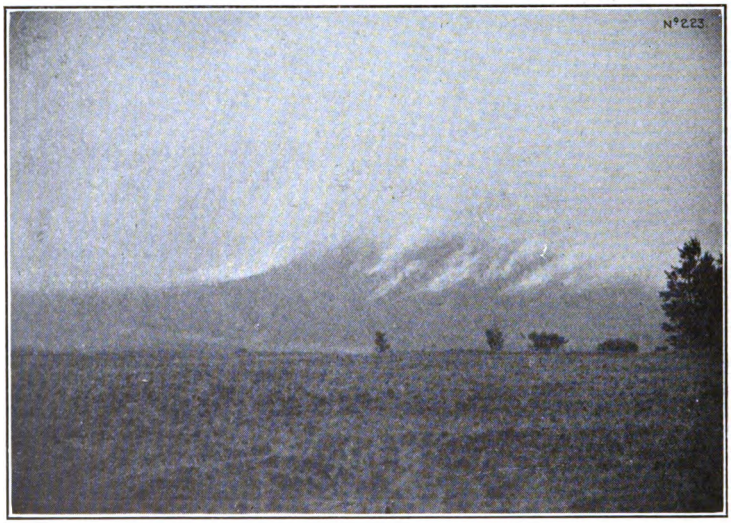
(9) Cumulo-Nimbus (**Cu.-Nb.**). A thunder-cloud with "anvil" finely developed.




(10) Stratus (**St.**). Level sheet of low cloud : below 3,000 ft.

FIG. 111.—CLOUD FORMS—*continued.*

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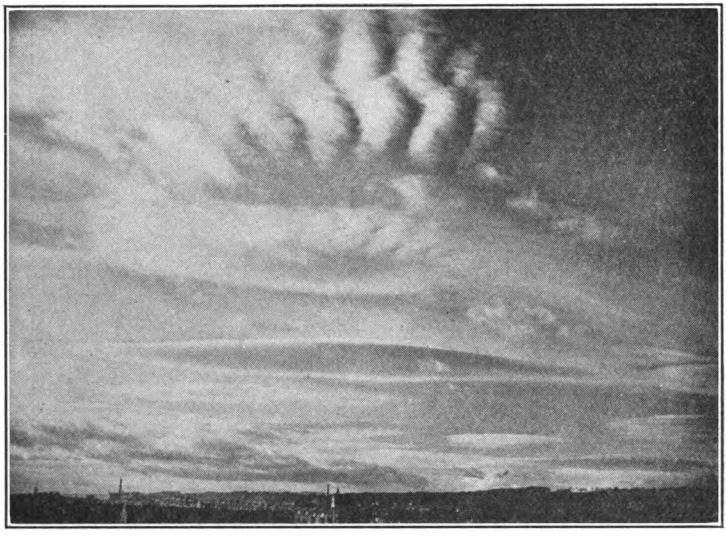
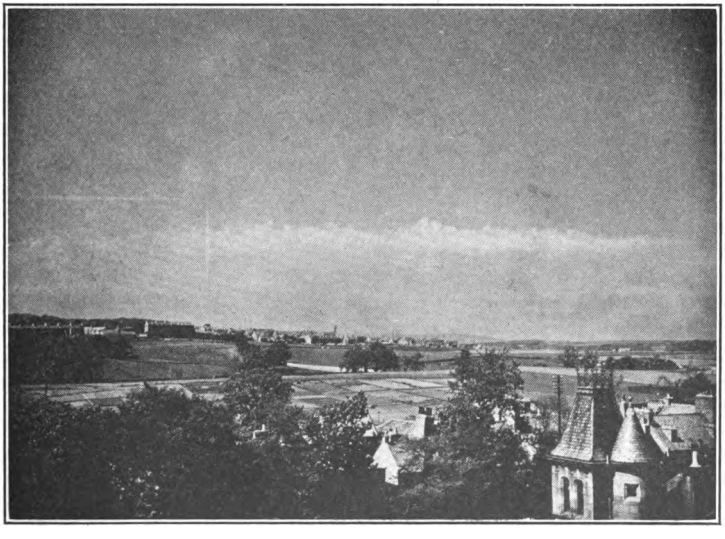


(11) Alto-Cumulus-lenticularis (**A.-Cu.-Lent.**). Almond-shaped banks of cloudlets at the alto-cumulus level.



(12) Alto-Cumulus-Castellatus. Little miniature cumulus rising in many heads from a more or less compact layer of alto-cumulus.

FIG. 111.—CLOUD FORMS—*continued.*

(Photographs selected from the collection of Mr. G. A. CLARKE of the Observatory, Aberdeen.)



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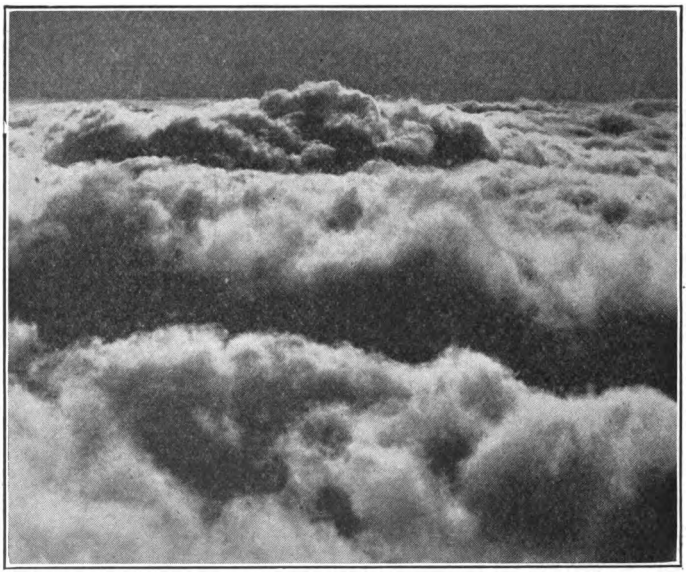
(13) A typical horizontal sheet of Strato-Cumulus (height 1,000 to 2,500 feet).



(14) A turbulent layer of Strato-Cumulus. The raggedness shows extreme bumpiness.

FIG. 111.—CLOUD FORMS—*continued.*

(Photographs taken from the air by Captain C. K. M. DOUGLAS.)

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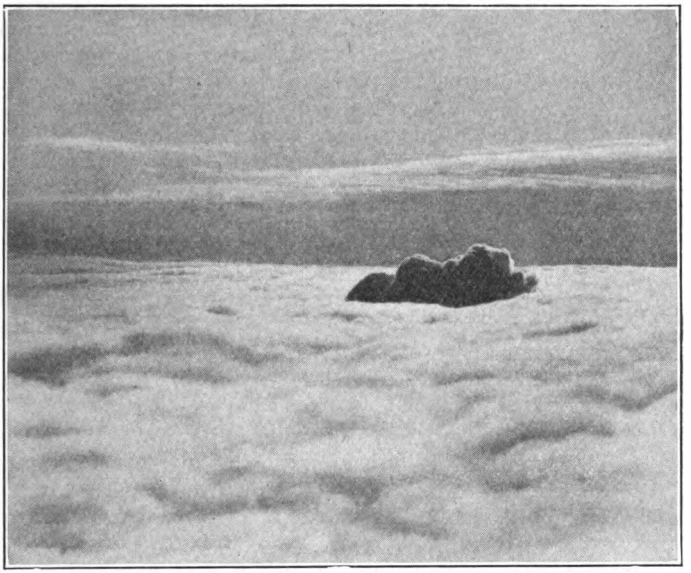
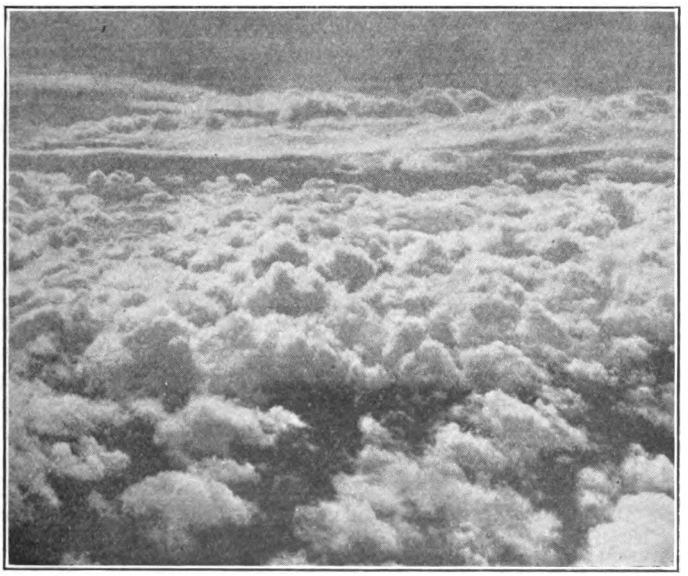


(15) Top of large Cumulus protruding 2,000 feet through a cloud-sheet. The height of the upper surface of the cloud-sheet was 8,000 feet.



(16) Fracto-Cumulus.

FIG. 111.—CLOUD FORMS—*continued.*

(Photographs taken from the air by Captain C. K. M. DOUGLAS.)

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2. *Convection.*—Owing to the irregular heating of the ground by the sun large vertical movements of air occur and a cumulus cloud forms at the top of each rising column. Between the clouds descending currents and clear sky occur. Such clouds usually form during the day and dissolve at night. On a very hot day, with moist air, cumulo-nimbus clouds are formed and thunderstorms may develop. Temperature falls with increasing height throughout the cloud. Such clouds are usually very bumpy.

Conditions favourable for the development of cumulus or cumulo-nimbus clouds also occur in the rear of a depression when a current of cold air meets a current of warmer air (the " cold front ") and undercuts the latter causing large-scale convectional movement (*see* para. 18).

3. *Gradual ascent of air over large area.*—This occurs in advance of a depression when a warm air current is advancing on a colder current (the " warm front ") (*see* para. 18). The warm air rises over the denser, colder air forming a sloping surface. The warm air may ascend to the Cirrus level and give rise to the cloud sequence shown in Fig. 112, ranging from high Cirrus cloud through alto-stratus to low nimbo-stratus. There is usually a temperature inversion at the boundary of separation.

It should be noted that, when flying towards the warm front, the base of the cloud becomes progressively lower. Although initially the base of the alto-stratus may be above 10,000 feet, the nimbo-startus may fall to 300 feet or lower. Also the pilot is flying in a direction opposite to that of the movement of the front, and if the latter is travelling rapidly, the change from high to low cloud will take place in a relatively short interval of time. Alto-stratus is comparatively free from bumps but nimbo-stratus may be very bumpy.

(*b*) *By eddies.*—When a current of cold air flows over a warmer surface, eddy motion is set up which causes mixing between successive layers of air. The mixing and consequent cooling may extend sufficiently far upwards for condensation to occur and a layer of strato-cumulus cloud to form.

The air above the cloud, being unaffected by the turbulent mixing, is warmer than the air lower down which has been cooled by the process. In other words, there is an inversion above the cloud layer. The turbulent mixing, when sufficiently vigorous, causes the clouds to assume the roll form characteristic of strato-cumulus.

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The air in and below such clouds is usually bumpy, while above them there is steady flying. Cloud of this type usually tends to break up in summer, but in winter it may last for days. Most cloud sheets are characterised by an inversion above them. Pronounced inversions are sometimes formed by the arrival of a current of warm air at a height of a few thousand feet. In cases there is a marked change of wind above the cloud. It should be noted that in a layer of strato-cumulus, cumulus or cumulo-nimbus may develop in isolated patches giving rise to areas of severe bumpiness. This phenomenon is illustrated in plate (15) of Fig. 111.

(*c*) *By mixing.*—If two air currents of different temperatures flow parallel to each other, mixing may occur at the boundary and a belt of cloud form. In such cases the cloud usually extends right down to the ground.

Stratus cloud is formed by the turbulent mixing of moist air in a layer above the surface of the ground. It frequently occurs in the early morning as a transition stage between night fog and clear day conditions. Such cloud usually has a very low base and frequently envelops high ground.

## 15. Precipitation

(i) *Rain* is produced by the condensation of the water vapour in the atmosphere. It has been seen that when the temperature of a mass of air containing water vapour falls sufficiently, a point is reached where the water vapour is condensed into fine particles of water, and a cloud is formed. If the process of cooling is carried still further by the ascending motion of the air continuing after condensation has commenced, the cloud particles grow in size until they are too heavy to remain suspended in the air, and rain falls. The nature of the rain-fall depends on the magnitude of the ascending currents of air, and, therefore, on the lapse rate.

Rain may be classified, according to the manner in which cooling is brought about, into three types :—orographic, cyclonic, and convectional.

(*a*) *Orographic rain* is caused by the interference of rising land in the path of moisture-laden wind.

A horizontal air current striking a mountain slope is deflected upwards, and the consequent dynamical cooling produces rain if the air is moist enough. Mountain ranges at right angles to the direction of the wind offer greater obstruction to the wind, and therefore are more likely to produce rain than mountain ranges which lie in the direction of the

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wind. In the case of isolated mountain peaks, the wind is often able to go round, and the amount of rain produced may be trifling. The prevailing wind of the British Isles is from the south-west and as this damp wind passes across the country the aqueous content decreases. A mountain range of a given height along the west coast would therefore produce a greater rainfall than a range of similar height and position relative to the wind in the east.

These orographic rains are typically persistent and usually widespread. Their great importance lies in the fact that the main controlling factor, namely the rising ground, is always operative, and naturally always in the same place. Thus a station on a hill is not only usually wetter year by year than a neighbouring station in a valley, but the proportion remains fairly constant. Some valleys, if they are surrounded by mountains on all sides, receive nearly as large a rainfall as the surrounding mountains, since air is generally rising as it passes across these valleys.

(*b*) *Cyclonic rain* is the rainfall associated with the passage of depressions. It is caused by a gradual ascending movement over a wide area, and is therefore a continuous steady rain, the rain drops falling through the air as soon as they are formed owing to the absence of any large vertical air currents.

(*c*) *Convectional rain* is caused by the heating of the surface ay e rs of the air. The warm air is frequently heavily charged with moisture taken up from the ground, from vegetation, or water surfaces. This type of rainfall is associated with a steep temperature lapse rate and strong ascending currents, and the process of rain formation is more complicated.

The rate at which raindrops fall through the air depends on the size of the drops. When first released their speed will increase until the air resistance is exactly equal to their weight, when they will continue to move at that steady speed, which is known as the *terminal velocity*. The stronger the ascending current, therefore, the larger is the size of the drops that can be supported by it, and consequently the heavier is the rainfall. There is, however, a certain limiting size of raindrop which can be generated: above this size the drop will break up into smaller drops. In consequence, if the speed of the ascending current is greater than a certain amount (about 1,600 feet per minute), no water drops can fall through it, but all will be carried upwards. In this way large accumulations of water can occur in a cloud, and if the ascending air currents suddenly cease, very heavy rainfall results.

(ii) *Snow* is precipitation in the form of ice-crystals of feathery or needle-like structure. The crystals may fall singly or a large number of them may be matted together in the form of large flakes.

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Snow occurs when the temperature conditions in the air are such that condensation is taking place near the freezing point. It is not uncommon for snow to occur in the upper air and to change to rain lower down, the precipitation reaching the ground in this form. Snow will therefore frequently be encountered while flying during the winter when it is raining at ground level.

(iii) The term *hail* properly denotes the hard pellets of ice of various shapes and sizes which fall from cumulo-nimbus clouds and are often associated with thunderstorms. A variety known as soft hail is small, white, opaque and soft, resembling little snow pellets.

Hailstones may attain a great size, stones as large as golf balls having been observed in Europe, and the recorded weights range up to 2 lbs.

Hail is formed in the same way as convectional rain already described, being raindrops which have been carried upwards in strong ascending currents of air to levels where the temperature is well below freezing point, and thus become frozen. They frequently make several upward and downward journeys in the cloud before becoming heavy enough to overcome the resistance of the rising air and finally falling to the ground. This accounts for the laminated structure of many hailstones. The stronger the upward currents the larger are the hailstones, so that large hailstones are evidence of dangerous flying conditions.

### 16. Ice accretion on aircraft

(i) In certain conditions ice may form on the wings and other parts of an aircraft in flight. When the rate of deposition is slow the formation is mostly crystalline and opaque and forms mainly on the leading edges with little change of aerodynamic shape. When, however, the deposition is rapid, mainly clear ice forms and adheres firmly to the surfaces. The leading edges then acquire a mushroom-shaped growth and the aerodynamic shape of the surfaces changes, causing rapid loss of lift. Danger also arises from pieces of ice becoming detached from the airscrew; this causes loss of balance and vibration, apart from the risk of pieces of ice striking the fuselage, cockpit, etc.

(ii) Ice deposition may occur in the following ways :—

(*a*) By direct change from water vapour to the solid state. This occurs when condensation takes place below freezing point, but more frequently below 25° F. A white crystalline deposit then forms on exposed surfaces (hoar frost). Deposition is slow and there is little adhesion.

(*b*) When flying in clouds in which supercooled water drops occur below 32° F. These drops solidify immediately

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on striking the surface of the aircraft, forming a deposit of feathery ice crystals (rime). Such deposition may occur at any temperature from 32° F. to below 10° F.

(*c*) When rain is falling through air having a temperature below the freezing point, it freezes immediately on striking the surface of the aircraft causing a rapid deposition of clear ice (glazed frost). Such deposition occurs in or below clouds with temperatures 1° to 3° F. below the freezing point. These conditions frequently occur at the end of a cold period in advance of the warm front of a depression (*see* para. 18), the temperature above the boundary of separation being above 32° F. while the temperature below it is lower than 32° F. The area in which glazed frost is formed may extend up to 100 miles in advance of the lowest part of the front.

(iii) Observations made in England show that ice accretion may occur in any type of cloud, but that deposits are heaviest in strato-cumulus, stratus, cumulus and cumulo-nimbus. It is likely to be encountered :—

(*a*) in any cloud with a temperature below 32° F. ;

(*b*) in any area where the ground temperature is below 40° F., particularly if there is rising ground to be crossed ;

(*c*) with rain at or near the ground and temperatures only a little above 32° F. In these conditions sleet and snow will be encountered at no great height ;

(*d*) at the end of a cold period as described in (ii) (*c*) above.

(iv) The conditions in which glazed frost forms (*see* (ii) (*c*) above) may be encountered at any level below the inversion between the two air currents. Consequently the deposition of ice can only be checked by climbing into the warmer air above the inversion. In other cases deposition can be checked by getting out of the cloud. When flying in strato-cumulus or stratus, there is less risk of ice formation when flying near the upper boundary of the cloud. If ice commences to form it is then possible to climb above the cloud where the air is warmer.

### 17. Weather in relation to wind currents

The variability of the weather in this country is largely due to its position, lying as it does in a transition zone. From north to south there is a transition from polar to sub-tropical conditions, while from west to east there is a transition from maritime to continental conditions. The result is that while the general air circulation in these latitudes is from west to east, many and frequent variations from this circulation take place, the pressure distribution rarely remaining unchanged for very long.

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The weather at any given place depends on the direction and past history of the prevailing currents at different levels with certain modifications depending on the season of the year, the time of day and the local topographical features. The wind circulation over a particular area at any time may be in the nature of a homogeneous current or may consist of two or more currents of different origin, and consequently of different temperatures and humidities, in juxtaposition. Speaking very generally, good flying weather is to be found in a homogeneous current, although exceptions to this are to be found. For example, if a current of cold air from high latitudes reaches this country after passing over a stretch of warm sea, the air becomes unstable owing to surface heating and showers readily develop. If such a current strikes high ground, the ascending movement may be increased and considerable rain may occur locally. Bad flying weather, however, is to be found more commonly at or near a discontinuity between two currents. The most important examples of such discontinuities occur in the type of pressure distribution known as a *depression.*

## 18. The depression

(i) On a weather map a depression appears as a system of closed isobars with the lowest pressure in the centre and the surface winds blowing counter-clockwise round the centre (in the northern hemisphere) with the usual deviation across the isobars from high to low pressure. Depressions usually move from south of west to north of east in western Europe and are frequently associated with strong south-westerly winds on their southern sides. Depressions moving in other directions are, however, by no means uncommon. The weather chart in Fig. 113 shows a depression centred over Northern Ireland and moving north-eastwards. The two broken lines emanating from the centre of the depression mark the boundaries between warm and cold air currents. On the south-east side of the depression, between the two lines, is an area of relatively warm air, the surface temperatures being of the order of 50° F. This area is called the *warm sector,* and it will be observed that within it the isobars are close together and the winds strong. A depression usually moves in a direction parallel to the isobars in the warm sector. On the other sides of the two broken lines are colder currents, the surface temperatures being about 10° lower than those in the warm sector. Remembering that the depression is moving north-eastwards, it is seen that the warm air is overtaking the cold air to the north of the broken line which extends eastwards from the centre of the depression. This line is called the *warm front.* The warm air being lighter, ascends over the retreating cold air forming a sloping surface.

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A typical section through a warm front is shown in Fig. 112. The slope of the surface between the two air currents varies according to the conditions existing, but is of the order of 1 : 100. The ascent of the warm air gives rise to the cloud sequence shown and as the front approaches rain begins to fall increasing in intensity as the clouds become lower. In advance

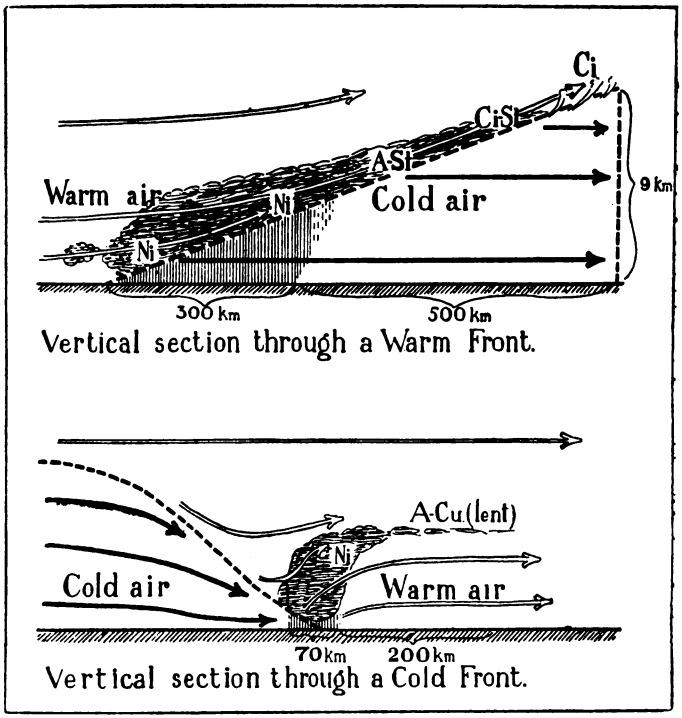


FIG. 112.—Rain and cloud formation.

of the warm front there is, thus, a wide belt of low cloud and continuous rain. The area over which rain is falling is shaded in the map in Fig. 113. After the warm front has passed the cloud lifts and tends to break, although since the air current in the warm sector is warm and moist, the weather usually remains cloudy and if there is any high ground, local rain may occur owing to the consequent ascent of the warm air. Along the broken line extending southwards from the centre of the depression the cold air is overtaking the warm air. This line is called the *cold front*. In this case the cold air being heavier undercuts the warm air, causing instability and ascending currents. The upward motion is more vigorous

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than the gradual ascent of air at the warm front, and usually gives rise to cumulus or cumulo-nimbus clouds and heavy rain which, however, is confined to a narrow belt as indicated in Fig. 113. A typical section through a cold front is shown in Fig. 112. In the rear of the cold front the air has usually come from high latitudes and is unstable, local showers occurring in it. Other phenomena associated with cold fronts are described in paras. 21 and 22.

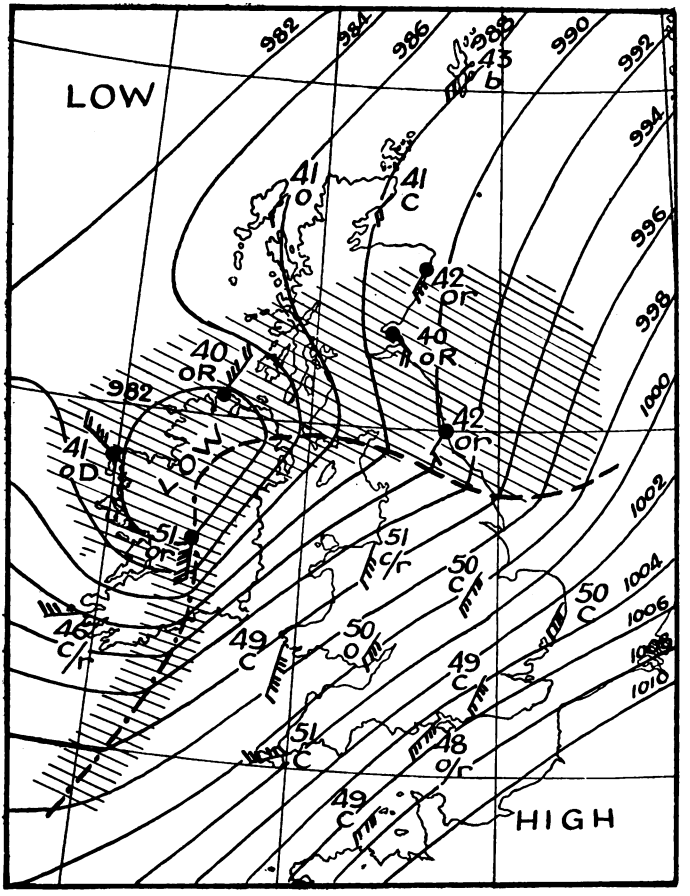


FIG. 113.—A depression.

(ii) The picture of a depression having definite warm and cold fronts must not be taken as typical of every depression. The well-marked structure described is only characteristic, as a rule, of recently formed depressions. As a depression advances

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the cold front gains on the warm front, and eventually overtakes it. The warm sector then disappears and a single front remains on the surface. This front, which is called an *occlusion*, may partake of the character of a warm or cold front according to whether the advancing air mass is warmer or colder than the air in front of the depression. The majority of depressions reaching the British Isles from the Atlantic have reached this stage of development.

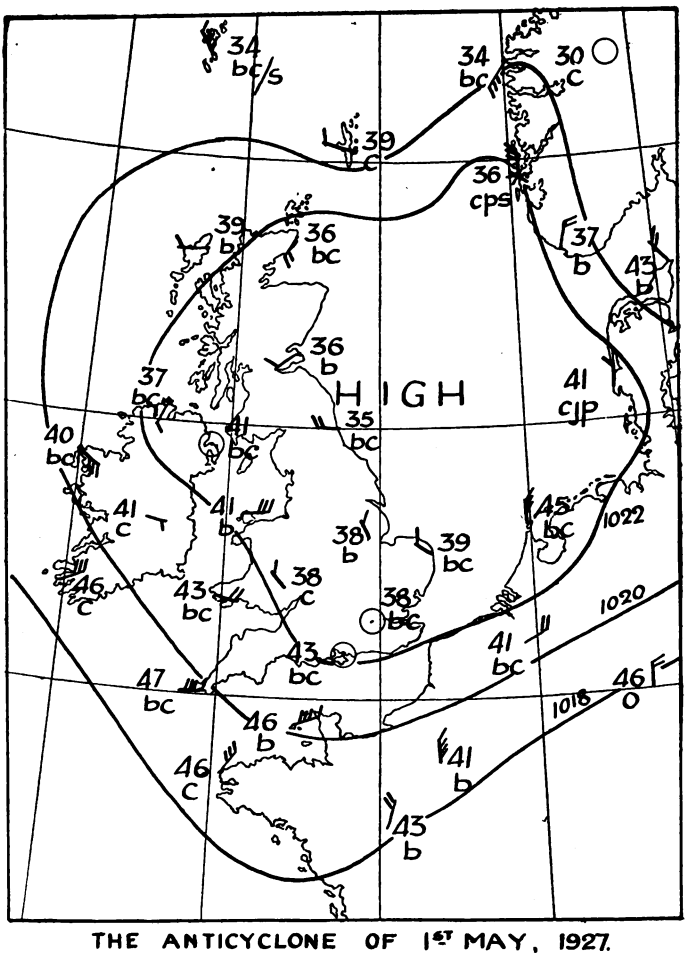


FIG. 114.—An anticyclone.

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### 19. The anticyclone

On a weather map an anticyclone, like a depression, is shown by a system of closed isobars, but with the highest pressure in the centre. The winds circulate clockwise round the centre (in the Northern hemisphere) and, near the surface, they tend to blow outwards from high to low pressure. The isobars are, normally, farther apart than in the case of a depression, an anticyclone being a region of light winds. A typical anticyclone is shown in the weather map in Fig. 114. The motion of anticyclones is usually slow and irregular ; they may remain without an appreciable change of position for days at a time. From the wind circulation it is evident that an anticyclone is a region of descending currents, although the rate of descent of the air is very slow. Conditions are therefore stable. In summer the weather is usually fine, but in winter, although the weather is quiet, and persistent rain is exceptional, conditions are much more varied. The weather is frequently cloudy, extensive sheets of stratus, and particularly strato-cumulus, formed as described in para. 14, covering the sky. Such cloud layers occur most frequently on the north-east side of the anticyclone. The absence of strong winds and the stable condition of the atmosphere are very favourable for the formation of fog. In fact, most of the fogs in autumn and winter occur in anticyclonic conditions.

### 20. Other types of pressure distribution

The depression and the anticyclone form the two main types of pressure distribution, but it is usual to describe the arrangement of isobars on any weather map with the help of four more acknowledged types.

The subsidiary type most commonly mentioned is the *secondary depression.* Sometimes in the neighbourhood of a large depression, usually on its southern side, the isobars take a bend outwards, marking the position of a small area of low pressure. Such a secondary depression usually travels forward in the same direction as the main low, but outstrips it in rate of travel. It usually produces much rain and frequently much wind. In the summer secondary depressions are normally shallow, and cause thunderstorms.

A *V-shaped depression* is a further extension of the secondary ; the isobars extend out a long way in the form of a letter V. The central line of the V obviously marks a region of abrupt change in the wind direction. It is really a well-marked cold front, and produces a rapid change in the weather from heavy rain to clear skies, and a large fall in temperature.

*A wedge or ridge of high pressure* is the region between two depressions where the isobars are shaped like an inverted V.

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The wedge usually extends polewards between the two lows which are skirting the northern edge of an anticyclone, and moves eastward with them. The front of the wedge is therefore a region of fine weather with north-westerly winds, rapidly becoming light in force as the axis of the wedge approaches; then the wind backs to south-west or south as the new depression comes along, and rain usually follows. A wedge represents the interval of fine weather between two rainy periods.

A *col* is a region between two anticyclones, like a mountain pass between two higher peaks. Since the wind is blowing round the two highs in a clockwise direction, the col is a region of light airs from very different directions which are being brought into close proximity. A col gives conditions for fog in cold weather and thunderstorms in hot weather.

### 21. Line squalls

(i) In para. 6 reference was made to the gustiness of the wind near the surface as a result of the friction set up between the moving air and the ground, a gust being defined as a temporary increase in wind velocity of the order of a fraction of a minute. Rapid increases of wind velocity lasting for some minutes also occur, and these may be associated with a temporary shift of the wind, and with heavy showers or even thunderstorms. Such changes of wind are termed *squalls*. Their method of occurrence may be understood from a consideration of the particular case in which squalls occur simultaneously along a line, sometimes hundreds of miles long, advancing across the country. To such the term *line-squall* is applied. A line-squall is invariably associated with a well-marked cold front and its passage is marked by some or all of the following characteristics, according to circumstances:

(*a*) A sudden change of wind direction, usually a veer.
(*b*) A sudden increase of wind speed.
(*c*) A rapid rise of barometric pressure.
(*d*) A sudden fall of temperature.
(*e*) Strong upward currents.
(*f*) Heavy rain or hail.
(*g*) Thunder and lightning.
(*h*) A long roll of cloud extending along the front.

(ii) When a cold front travels across the country, the friction at the surface retards the cold air in contact with it, while the cold air at some height above the ground moves forward unimpeded. The result is that the cold air assumes the form of a wedge with its point some distance above the ground.

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When the tip of the wedge comes overhead at a station the barometer commences to rise rapidly and continues to do so as the vertical thickness of the denser cold air above the station increases. The abrupt pressure changes cause a rapid veer of wind, usually from a southerly point to north-west, and a short sudden increase of wind speed, these phenomena constituting the squall. Under the overhanging portion of the wedge of cold air there is warm air so that the overhanging portion is unstable. The breakdown of this unstable arrangement gives rise to intense vertical currents as the warm air rises over the front edge of the cold wedge. The squall cloud forms near this front edge, the well-known roll form being imparted owing to a compensating downward current just behind the edge. If the warm air mass in advance of the cold front is initially unstable, the ascent of air will not be confined to the lower layers but will continue to considerable heights forming towering cumulus clouds with the possibility of heavy rain or hail and thunder and lightning.

(iii) Line-squalls usually travel from a direction between north-west and south-west. Occasionally they move from north to south or from south to north. There is very rarely an easterly component in the motion. Rates of travel of 30 m.p.h. are quite common and speeds of 60 m.p.h. are not unknown. A line-squall does not usually advance at a uniform rate along its whole length.

(iv) Since there are cold fronts associated with all active depressions of temperate latitudes the frequency of occurrence of line-squalls of varying degrees of intensity is high, but for every severe squall there may be many of only moderate or slight intensity. The horizontal length of a line-squall may be anything up to 1,000 miles. The length of life is often at least twenty-four hours. A line-squall would usually become less intense, or die out altogether, when an occlusion is formed, but even afterwards the occlusion may have the character of a cold front and the line-squall persist for a further considerable period before dying out. It is important to note that, just as there is a considerable variation of speed of advance along the front so the intensity of the associated phenomena may vary at different points.

(v) Although line-squalls are associated with the cold fronts of moving depressions of temperate latitudes, line-squall phenomena are also encountered in the Tropics, often in an intense form. In many tropical countries the daily sea breeze often sets in as a line-squall. The " Nor'-westers " of Bengal, the " Sumatras " of the Malacca Straits, the " Pampero's " of the Argentine and the " Southerly Busters " in south and south-east Australia are all line-squall phenomena.



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## 22. Thunderstorms

(i) For the formation of a thunderstorm a very steep temperature lapse rate is necessary giving rise to strong vertical currents. Thunderstorms are associated with heavy cumulus or cumulo-nimbus clouds with strong ascending currents in the region of the front of the cloud and are frequently accompanied by hail. A fully developed thunderstorm may be described as one in which heavy rain or hail, lightning and thunder occur. The lightning flashes are evidence of the vast quantity of electrical energy released in a thunderstorm and the question naturally arises as to the origin of this energy.

(ii) There is always some electrical force in the earth's atmosphere, especially near the surface, but in fine weather this is relatively small and for most practical purposes may be neglected. The electrical field which exists in all regions during fine weather is called the normal field.

(iii) As soon as the weather becomes disturbed more intense electrical forces make their appearance. During fog the normal electrical field becomes greatly intensified and in some cases may become so strong that some electrical discharge takes place from the ends of pointed metallic conductors connected to the earth. If, however, the fog is not accompanied by precipitation the electrical fields never become sufficiently strong for disruptive discharges to take place and therefore fogs in themselves do not produce dangerous conditions.

(iv) As soon as precipitation in any form—rain, snow, sleet or hail—commences, an entirely new set of electrical conditions is introduced. It was pointed out in para. 15 that the largest raindrops which can persist in the air require an upward current of 1,600 feet per minute to support them and that, above this speed, the drops become unstable and break up into smaller drops.

Laboratory experiments have proved that when a water drop suddenly breaks up in the air into a number of smaller drops considerable electrical separation takes place. The water becomes positively charged while the air becomes negatively charged. When the drops break in an ascending current of air the positively charged water-drops, on account of their weight, lag behind the ascending air which carries the negative charge. This results in the negative charge being removed from the positive charge, the former being carried into the upper part of the cloud and the latter remaining in the lower part or falling to earth as rain. The separation of electricity into different parts of the cloud will set up large electrical fields.

It is important to note that the electrical effect is produced after the precipitation is formed and has commenced to fall relatively to the air in which it is supported. Further, the air

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must be moving upwards if any large quantity of electricity is to be developed; generally speaking, the more violent the ascending currents the more efficient they will be in producing electrical effects.

(v) With these considerations in mind it is easy to understand the efficiency of different kinds of weather in producing electrical effects. Commencing with fine weather we have only the normal electrical field which is small and for most purposes unimportant. When fog or cloud are formed, no new electricity is produced and all that they can do is to modify the existing normal field; but the electrical fields produced in this way are not strong enough to be of much practical interest. As soon as some of the cloud particles become sufficiently large to fall through their neighbours, the possibility of the production of electricity and its separation arises. If the rain or snowfall is slow and steady, as in the case of the precipitation associated with a warm front when the whole sky is covered with cloud which has a very slow and regular ascent, the production of electricity is slow and the electrical field does not rise to high values although it may be higher than during fine weather.

(vi) When the atmosphere becomes unstable, as at a cold front, or in polar air, or during a hot summer day, the ascent of the air no longer takes place slowly and steadily over a vast area, but tends to rise in local ascending currents each one of which is marked out by a cap of cloud surrounded by clear air. As the ascent progresses and becomes more violent showers of rain or snow are formed. The conditions are then suitable for efficient separation of electricity. As the ascending currents, and with them the precipitation, become more extensive and more intense so the electrical separation increases. The accumulation of large electrical charges results in strong electrical fields, and as soon as these fields become large enough electrical discharges commence. The discharges are at first probably small and local, but as the field increases still further the large disruptive discharges which we call lightning take place and we have a thunderstorm.

With still greater increase in the ascending currents hail is formed and the lightning becomes more frequent and violent. The presence of hail is proof that rapid ascending currents exist and violent electrical effects may be expected.

(vii) The necessary conditions as regards instability for the formation of a thunderstorm may occur in the following ways:—

(*a*) Strong surface heating of the ground on clear days. Thunderstorms formed in this way usually occur in the afternoon. They are most frequent in early summer when the upper air is relatively cold.



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(*b*) The setting in of a cold upper current of air over a warm surface current. Such conditions are produced over England when a cool south-westerly wind sets in above a warm current from the south-east. They frequently occur in summer when a fine spell of anti-cyclonic weather is breaking down, and unsettled conditions are commencing to spread from the Atlantic.

(*c*) The undercutting of warm moist air by a cold current. These conditions are associated with a cold front, thunderstorms frequently accompanying line-squalls. Storms of this type occur at any time of year.

(*d*) In unstable polar currents in which the development of showers is often accompanied by thunder. These conditions occur more particularly near the western seaboard in winter.

(viii) Thunderstorms are neither so numerous nor so severe in the British Isles as in the Tropics. They are most frequent in the eastern and midland districts and a large majority occur in the summer half year, especially from May to August. In the western coastal districts the storms are of types (*c*) and (*d*) above and occur with nearly equal frequency in the summer and winter seasons. There are many hot summer days, especially in anti-cyclones, when the necessary conditions for the formation of a thunderstorm, viz., an adequate supply of moisture and a steep temperature lapse rate, are not fulfilled so that the hottest summers are not necessarily the most thundery. The requisite conditions exist most frequently at this season in shallow depressions or in cols. With conditions in the upper air favourable, it is possible for severe storms to occur at night, provided there is some initial impulse to start the cloud formation, e.g. the convergence along a cold front.

### 23. Lightning and aircraft

(i) It has been seen that in a thundercloud the breaking-up of the water drops results in a separation of electricity, the water after breaking-up having a positive charge while the cloud particles become negatively charged. The electricity is attached to the cloud or rain particles and as each of these particles is surrounded by non-conducting air, the charge cannot leave its carrier but must travel wherever that carrier goes. The electricity thus becomes localised and bound in definite regions of the cloud. Each concentration of electricity is the origin of an electrical field of force which is most intense at the edge of the region containing the charge As the electrical strength of the air breaks down where the field is the most intense and from this point a lightning flash starts, it is clear that a flash may start within the cloud and pass from

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a region of positive to a region of negative charge all within the cloud ; or it may start under one charge—but well within the cloud—and pass from there to the ground.

(ii) The presence of an aeroplane may affect an electrical discharge in two ways. Before an electrical discharge can start the electrical force must reach that intensity which breaks down the air. If into a part of the electrical field which is near but slightly below the sparking value an electrical conductor is introduced, the conductor concentrates the field and may raise the intensity above the sparking value. A discharge then starts at the conductor which may develop into a lightning discharge. If, therefore, an aeroplane flies near to that part of a cloud which carries a high charge it may initiate a lightning discharge.

The second way in which an aeroplane may influence a lightning discharge is to be by chance near to the path of a discharge which has started elsewhere. When a discharge starts at any point it progresses by building for itself a conducting channel through the air. The general direction of propagation of a discharge is towards the electricity of the opposite sign to that which caused the breakdown. Thus, if a discharge starts in a region of the cloud which has a positive charge the channel will grow either towards the negative electricity in another part of the cloud or to the negative electricity induced on the surface of the ground. If there is a high conducting path—such as the metal in an aeroplane—within striking distance of the channel as it lengthens, the channel will be attracted to this and pass into it at one end and out at the other. As the majority of flashes below a cloud strike downwards to the earth the air path may be appreciably shortened by a trailing aerial. Generally speaking, the greater the linear length of a conductor the more risk there is of its providing a short circuit for a lightning flash. Thus the long wire used in towing targets by aeroplanes may provide an attractive path for a discharge even though it lies in a horizontal direction ; for the electrical field is by no means always vertical.

(iii) The conclusion to be drawn from these considerations is clear ; the aircraft should, if possible, avoid the regions where there is great electrical activity. As already explained, these regions are the parts of the cloud where the most violent ascending currents occur and are generally situated some distance within the cloud itself. If therefore an aeroplane is caught in a thunderstorm it is best both from the point of view of dangerous electrical discharges and dangerous vertical air currents to fly well below the cloud and never through it, if that can be avoided.

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(iv) If an aeroplane, without an aerial, is near to a lightning discharge it has not a very great attractive power because its linear dimensions are not great. If, however, it is struck the discharge will enter and leave at those points which give the longest path in the direction in which the discharge is travelling. The actual direction of the field will determine the exact points in each individual case, but experience shows that they are most commonly the tips of the wings, the nose of the plane and the end of the tail. If all these points are connected together by one or more metallic paths, the total cross section of which is of the order of half a square inch, the flash can enter and leave the plane without doing any damage. In most planes there is sufficient metal paths to satisfy this condition, but in machines largely built on wooden frameworks there may be some section in which the metal paths are only meagre and a structural wire or a control wire has to take a heavy load, and there is then danger that this member may be burnt out. The more metal there is in the framework of the machine the less the danger of this occurring. It is clearly desirable that the current should have open to it every possible path between the point where it enters and the point where it leaves so as to decrease the resistance and to increase the effective cross-section of the conducting path. This will only be attained if every piece of metal in the aeroplane is bonded *at both ends* to other metal conductors.

(v) On machines without aerials there is practically no danger to the personnel, for the cockpit is generally situated within such a mass of metal that there is little chance of any part attaining a high electrical potential relatively to any other part, so that there is little tendency of the discharge to pass into the human occupant.

The position, however, is much more serious if the machine has a trailing aerial. In the first place the aerial extends the linear dimensions of the conductor and generally in the direction which the flash wishes to take. Thus a machine with an aerial is more likely to be struck than one without. Further, the aerial goes directly into the cockpit and is not directly connected to the main mass of bonded metal of the aeroplane which takes the place of a normal " earth ". This will conduct the high potential current of the flash right into the interior of the plane and through the numerous " leads " of the wireless set into dangerous proximity of the wireless operator, and of anyone wearing headphones. The most important thing therefore to be done when it is known that the plane is in a danger area, or is about to enter a danger area, is to wind in the aerial. It is not sufficient just to " earth " the aerial, for this does not reduce the attraction which the aerial exerts on a near discharge, or the tendency to initiate a discharge. Also

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an earthed aerial is almost certainly to be melted if the plane is struck. The aerial should always be earthed before the operator commences to wind it in, otherwise he will be in considerable personal danger if the plane is struck while he is handling the winch.

(vi) The wireless operator can assist the pilot in deciding when dangerous conditions exist by noting any considerable increase in the number or strength of atmospherics. He should inform the pilot who will consider this information together with the weather conditions in the region towards which he intends to fly. If the pilot considers it desirable, he will order the wireless operator to earth and wind in the aerial. The pilot should endeavour to issue this instruction in plenty of time for the aerial to be wound in before the real danger zone is reached. If the danger zone—characterised by heavy rain, hail, snow or lightning—is reached before the aerial can be wound in, the aerial should be immediately earthed and the aircraft flown out of the storm as quickly as possible, even if that necessitates flying back on its course. As soon as conditions allow the aerial should then be wound in when the pilot will be in a position to consider whether or not he should proceed on his course through the storm.

(vii) *Static charges.*—When an aeroplane is flying through a region where there is an intense electrical field different parts of the machine will be in regions at very different potentials. If the machine were completely of metal this would lead to no differences of potential within the machine itself for a metallic conductor must have the same potential everywhere. If, however, there are a number of metal pieces not all bound together these will take up different potentials and shocks may be experienced when these metals are touched.

In a similar way the aeroplane as a whole may become charged when flying through an intense electrical field, owing to the induced charges escaping through local brush discharges or even through the exhaust gases of the engine. Any such charges are rapidly dissipated as soon as the machine flies out of the electrical field; for the engine exhaust then acts as efficiently as a charge dissipater as it had previously acted as a charge collector. If however the machine lands while still in the intense field it may cause a spark on landing.

## 24. Instructions for preparing weather reports

(i) Weather reports for aviation purposes are transmitted in the abbreviated form of the International Code (Copenhagen, 1929). They include observations of the following elements which do not require the use of instruments :—weather, cloud, visibility and ground wind.

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The standard form of the code is :

$$IIIC_LC_M \qquad wwVhN_L \qquad DDFWN$$

The meanings of the symbols and the specifications of the different scales are given in appendix XV. The index figures (III) are fixed for each station. Each of the other letters is represented by one of the figures 0 to 9, the appropriate figure being selected from the table in appendix XV. Two figures are given for present weather (ww) on the scale 00 to 99 while wind direction (DD) is also represented by two figures on the scale 01 to 32. The following instructions are given for the guidance of Duty Pilots and others charged with the preparation of weather reports. In the case of requested weather reports it is only necessary to give the second and third groups of the code (*see* K.R. & A.C.I., para. 728).

(ii) *Forms of low and medium cloud* ($C_LC_M$)—First examine the sky and note what types of clouds can be seen. Illustrations of the different cloud forms are given in Fig. 111. Select from the code for $C_L$ the code figure which most nearly represents the state of the sky as regards the type or types of low cloud observed. *This will give the figure for* $C_L$. Then select from the code for $C_M$ the code figure which most nearly represents the state of the sky as regards the type or types of medium cloud observed. *This will give the figure for* $C_M$. If it is impossible to decide which code figure should be used for the form of low or medium cloud, replace the corresponding letter $C_L$ or $C_M$ by a hyphen. If there are no low or medium clouds present, then the appropriate letter $C_L$ or $C_M$ should be coded as 0.

(iii) *Amount of low cloud.*—Next observe the number of tenths of sky covered by low cloud of all types, 0 representing a sky which is entirely free from low cloud and 10 a sky which is completely covered with low cloud. From the code for $N_L$ select the code figure which represents this amount of cloud. *This will give the figure for* $N_L$. *It should be noted that the code figure is usually different from the number of tenths of sky covered with cloud.* For example, special code numbers are allotted to a " trace " of cloud, that is, when there is less than one-tenth of cloud present ; to the case in which there are more than nine-tenths of cloud but the sky is not entirely covered, small openings being visible ; and to the case in which the sky is completely obscured by fog.

(iv) *Total amount of cloud.*—Finally, estimate the number of tenths of sky covered by all types of cloud (low, medium and high) and select from the code the code figure representing this amount. *This will give the figure for* N. Note carefully that this number (N) is the total amount and not the amount of the medium cloud as reported by $C_M$. For example, if there were

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two types of cloud present, Strato-cumulus and Alto-cumulus, the amount of Strato-cumulus being 5 and the apparent amount of Alto-cumulus being 3, then two-tenths of the sky would be blue sky with no cloud on it and eight-tenths would be covered with cloud. The figure to be reported for N would be, therefore, 5 (seven to eight-tenths).

(v) *Procedure in case of fog.*—If the sky is obscured by fog, then $C_L$ will be reported by a hyphen, $C_M$ will also be a hyphen and $N_L$ and N will be 9 (sky obscured by fog). If the sun or stars can be seen through fog or mist and there is no evidence of cloud above the fog or mist, the amount of cloud N should be taken as 0, and $C_L$, $C_M$ should each also be reported by the figure 0. If cloud can be seen through the fog or mist the amount of cloud should be estimated as well as possible and the form or forms noted to the best of the observer's ability. The cloud forms and cloud amount should then be reported in the ordinary way as if fog or mist were not present.

(vi) *Height of base of cloud.*—The fourth figure of the second group (h) is to be used for reporting the height of the base of the cloud above the level of the ground at the station. A table giving the relation between the figures to be telegraphed and the actual height of the cloud is given in the code for h. When there is detached low cloud, e.g., fragments of fracto-stratus or fracto-nimbus at a lower level than the base of the general type of cloud reported by $C_L$, the value of h should refer to the general type of cloud reported by $C_L$, the form and height of the fragments of low cloud being given by a note in plain language added to the message, e.g., fracto-stratus 3.

The height of the cloud should be estimated to the best of the observer's ability but, whenever possible, a report should be obtained from a pilot who has been to the cloud level. Where the height of the cloud base is estimated to be approximately at one of the 100 feet or 1,000 feet levels which separate consecutive code numbers (e.g. 600 feet),the larger code number should be chosen if the cloud is judged to be above the level and the lower number if it is judged to be below the level. If the cloud is judged to be exactly at the level the lower code number should be selected. For example, if the base of the cloud is estimated to be exactly at 3,000 feet, h should be 5 and not 6.

(vii) *Present weather.*—A table showing the figures corresponding with the different weather conditions is given in the code for ww.

As a general rule, the largest number in the table which describes appropriately the present weather and the general character of the weather must be selected.

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One of the numbers 50–99 must be used if precipitation is occurring at the time of observation or has occurred within ten minutes or less of the time of observation.

Whenever a figure corresponding to the description " intermittent " is used the fog or precipitation must not have continued without break during the last hour.

Figures 20–29 must never be used when precipitation is actually occurring at the time of observation or within ten minutes of that time.

Figures 30–49 must be used only when the visibility is less than 1,100 yards, and there is no precipitation at the time of observation or within ten minutes of that time.

N.B.—Figures 35–39 refer to storms of drifting snow caused by the wind *raising* the snow from the ground, when it is not snowing in the ordinary sense of the term, i.e., when no more snow is coming down to the ground than is raised from the ground by the wind. When it is snowing in the ordinary sense of the term figures 35–39 must not be used even if the snow is also drifting in the wind.

Figures 80–89 must only be used when the precipitation is of the shower type, and when precipitation is actually falling at the time of observation. The clouds which give showers are isolated clouds, and the showers are therefore always of short duration. Between the showers there is a definite clearance unless stratiform clouds are filling the interstices between the shower clouds.

The figures 20, 30, 40, 50, 60, 70, 80 and 90 should not be used unless the observer is unable to describe the phenomenon by one of the other code figures or is in doubt as to the exact description of the weather phenomenon observed.

(viii) *Past weather*.—One figure is used in reporting past weather. A table giving the relation between the numbers and the past weather is given in the code for W.

In using this code the number is taken which describes the most important feature of the past weather not already reported by the two figures for "present weather". In any case in which the two figures for " present weather " describe fully the past weather also, then the appropriate single past weather figure is reported in confirmation, e.g. :—in the case of heavy continuous rain without fog or mist the present weather figures would be 66 and the past weather figure would be 5.

For stations making regular reports at fixed hours the period covered by the figure for past weather will be 7 hours in the case of observations made at 0100, 6 hours at 0700, 6 hours at 1300 and 5 hours at 1800 G.M.T.

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In the case of observations made at 0400, 1000 and 1600 G.M.T. the period will be 3 hours, while at 2200 G.M.T. it will be 4 hours.

For reports intermediate between the hours stated above, whether they be routine observations or special reports of sudden changes in the weather, the figure for past weather will refer to the period since the last report, but this period must never exceed 6 hours. In the case of the first report of the day, if this is made at an hour other than one of those enumerated above, the period covered by the figure for past weather will be 1 hour.

In the case of requested weather reports the period covered by the figure for past weather will be 1 hour.

(ix) *Visibility*.—The horizontal visibility, or approximate distance at which objects can be distinguished, is reported by one figure. Select a number of objects at the distances given in the table for V in appendix XV. Take the most distant object which is visible, then use the table to obtain the figure to be reported. For example, if the object at 2,200 yards is the most distant object visible, then objects at 4,400 yards are *not* visible and the figure to be reported is 5.

An object is regarded as being visible if the nature of the object can be determined by its appearance, e.g., if the object is a tree and it can be distinguished as a tree.

The distances of the objects should be as nearly as possible those given in the table; but a variation of 10 per cent. on either side is allowed so that the most suitable objects available may be used.

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## CHAPTER XVIII.—TIME

### 1. The measurement of time

(i) For all purposes, the measurement of time is of fundamental importance. One of the most primitive measures of time is the hour glass, which defines the particular interval of time given by emptying sand from the upper bulb into the lower. The swing of a pendulum defines another interval of time. A clock or watch is merely a more complicated mechanism which indicates on a dial the number of swings of a pendulum or oscillations of a spring that have occurred since a particular instant. No mechanism is perfect, so no mechanical contrivance is capable of keeping perfect time.

(ii) The rotation of the Earth provides the means of obtaining absolutely uniform intervals of time. Suppose that a star is on the observer's meridian at a particular instant. Owing to the rotation of the earth about its axis, the star appears to travel westwards across the sky. When next the star reaches the meridian, the earth has described one complete rotation about its axis. The interval of time defined by the two consecutive transits of the star across the meridian is a perfectly definite unit of time, and it measures a complete rotation of the earth. It is known that the earth rotates uniformly about its axis, and so the unit of time obtained is a definite and constant unit. This unit is called a *sidereal day*, and time measured according to this unit is *sidereal time*.

(iii) For purposes of everyday life, another unit of time is adopted. The most important heavenly body, as far as the inhabitants of the earth are concerned, is undoubtedly the Sun. The interval between two consecutive transits of the sun over an observer's meridian is called an *apparent solar day*. When the sun is on the meridian it is *apparent noon* at that place.

(iv) Owing to the fact that the earth's path round the sun is an ellipse and not a circle, and that its plane is inclined to that of the equator, the sun appears to cross the sky at a speed which varies slightly from day to day. For this reason, the apparent solar day is not so definite a unit of time as the sidereal day, and it is impossible to construct a clock or watch to keep apparent solar time. The unit which is actually used is the *mean solar day*, which is the average of all the apparent solar days throughout a large number of years. There are 365·24219 mean solar days in a mean solar year.

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The mean solar day at any given place may also be defined as the interval of time between two consecutive transits of the *mean sun* over the meridian of the place ; the mean sun being an imaginary celestial body definitely related to the true sun, which is considered to move with a uniform speed which is equal to the average speed of the true sun.

**2. L.M.T. and G.M.T.**

(i) The unit of time, the mean solar day, is divided into 24 hours, and the system of time which results is known as *local mean time.* The beginning of the day at any given place is midnight and is called 0 hours L.M.T. Noon is called 12 hours L.M.T. and is the instant when the mean sun is on the meridian of the place. The L.M.T. of two places in different longitudes will differ by an amount corresponding to their difference of longitude. It is consequently necessary to have a standard time, or standard meridian, to which the L.M.T. of all places can be referred. The meridian of Greenwich Observatory is chosen to be the standard meridian.

The local mean time at Greenwich is the standard to which all events can be referred. It is called *Greenwich mean time* or G.M.T.

(ii) The mean sun moves westwards through 360° in exactly 24 hours, so that the difference in time between two places 15° apart is one hour, and so on in proportion. As the earth rotates from west to east, easterly meridians will pass under the mean sun earlier than that of Greenwich: hence the time of a place east of Greenwich is in advance of Greenwich time, i.e., L.M.T. for any given instant is greater than G.M.T. at the same instant. Similarly, for a place west of Greenwich, L.M.T. is less than G.M.T. Hence the rule :—

*" Longitude east, Greenwich time least ;*
*Longitude west, Greenwich time best."*

A useful table for converting longitudes into time is as follows :—

360° = 24 hours.
15° = 1 hour.
1° = 4 mins.
1′ = 4 secs.

As an example ,find the difference in time between Greenwich and a place in Long. 62° 34′ W.

| | | |
|---|---|---|
| 60° | 0° | = 4 hours. |
| 2° | 0′ | = 8 mins. |
| 0° | 30′ | = 2 mins. |
| 0° | 4′ | = 16 secs. |
| 62° | 34′ | |

Therefore the L.M.T. of the place is 4 hours 10 mins. 16 secs. *behind* G.M.T.

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(iii) *British summer time* is a purely arbitrary arrangement in Great Britain by which, during a certain period of the year, clocks are set one hour ahead of G.M.T. This arrangement was made to make more hours of daylight available during the summer months.

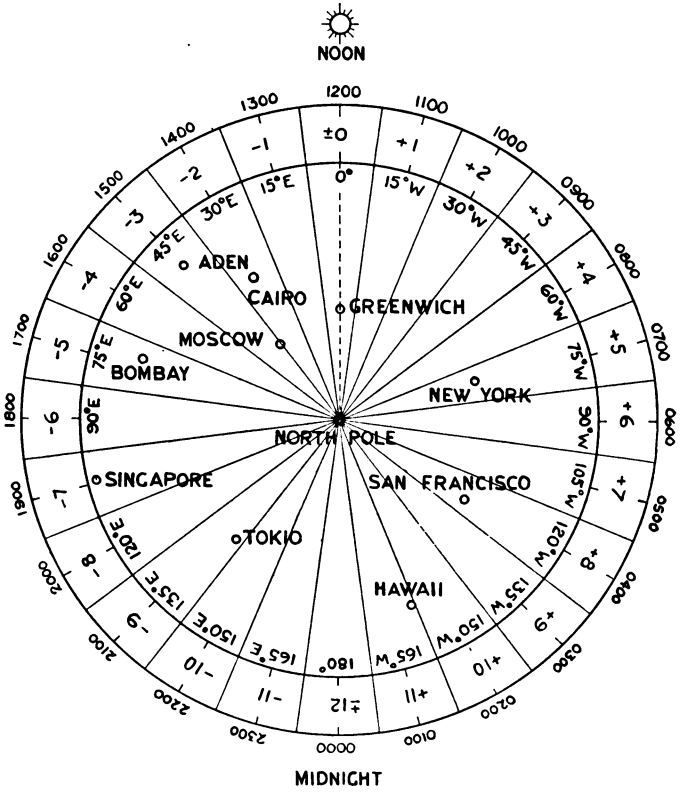


FIG. 115.—Local mean time and zone time corresponding to 1200 hours G.M.T.

### 3. Zone time

(i) If every place of the earth kept L.M.T. appropriate to its meridian, endless confusion would be caused. This will be seen when it is recalled that even in a small country like England, there is a difference of time of approximately 30 minutes between the east and west coasts. To avoid this confusion, the surface of the earth is divided into *time zones* by means of meridians 15° or one hour apart. Zone 0 is that of Greenwich, and lies between 7° 30′ E. and 7° 30′ W. All places between these meridians keep G.M.T. Zone + 1 is

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that between the meridians 7° 30′ W. and 22° 30′ W., in which the time kept is 1 hour behind G.M.T.; Zone — 1 is that between 7° 30′ E. and 22° 30′ E., in which the time kept is 1 hour in advance of G.M.T.; and so on (*see* Fig. 115). All places in any given zone, whatever their longitude, keep the same time for their everyday requirements, and so avoid confusion. This is called *zone time*, and is the L.M.T. of the central meridian of the zone.

(ii) A simple way to find in what zone a place is situated is to convert the longitude of the place to time and take the nearest whole hour.

*Example.*—In what zone is a place whose longitude is 130° E.?

130° = 8 hours 40 mins. (Using the conversion table in para. 2 (ii) above.)

The place is therefore in Zone — 9.

In this example, the zone time would be 9 hours in advance of G.M.T., while the L.M.T. would be 8 hours 40 minutes in advance of G.M.T. Thus at 1115 hours G.M.T., for example, the zone time would be 2015 hours and the L.M.T. 1955 hours.

(iii) In practice, the zones are modified somewhat, according to the geographical configuration of the countries concerned, and some countries keep the L.M.T. of their central or other specified meridian. In large countries and at sea, however, the boundaries are usually the actual meridians.

### 4. Sunrise and sunset

(i) Tables for finding the times of sunrise and sunset for every day in the year will be found in the *Abridged Nautical Almanac*, which is published annually. The tables give the L.M.T. of sunrise and sunset for northern latitudes from 0° to 60°.

(ii) As explained in para. 3, the time kept at any place is the L.M.T. of the central meridian of the zone in which the place is situated or the L.M.T. of the meridian chosen as a standard for measuring time in the particular country concerned. In the sunrise and sunset tables this is called *standard time* and the meridian to which the time refers is called the *standard meridian*.

(iii) In order to convert the L.M.T. given in the tables to standard time it is necessary to add or subtract the number of minutes which the place is west or east respectively of the standard meridian.

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*Example.*—Find the standard time of sunrise at a place in Lat. 50° 00′ N., Long. 57° 30′ E., on March 4th, 1935.

Convert the longitude to time :—

| | | |
|---|---|---|
| 45° | = | 3 hours |
| 12° | = | 48 mins. |
| 30′ | = | 2 mins. |

Therefore 57° 30′ E. = 3 hours 50 mins. E.

Thus the zone is — 4 and the standard meridian of the zone is 4 hours E. of Greenwich.

The place is therefore 10 minutes W. of the standard meridian.

From the tables, L.M.T. of sunrise March 4th, 1935 = 6 hrs. 40 mins.

(add) 10 mins.

Standard time of sunrise at the given place = 6 hrs. 50 mins.

(iv) In order to avoid the necessity for a special table for southern latitudes, the time of sunrise or sunset for a place in southern latitudes is taken from the tables at the corresponding northern latitude, but for a date about six months sooner or later, and a correction is applied to give the correct L.M.T. A table showing corresponding dates and the corrections to be applied is given in the Nautical Almanac immediately following the sunrise and sunset tables.



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## CHAPTER XIX.—GROUND ORGANISATION

### 1. Duties of the navigation officer

The duties of the navigation officer of a service unit are laid down in A.P. 958, The King's Regulations and Air Council Instructions, para. 760. These duties fall under three headings :—*instructional, technical* and *administrative.*

(i) *Instructional.*—The navigation officer will act as instructor in navigation to the pilots and air gunners of the unit. He may be called upon to deliver lectures but, as a general rule, instruction should be individual rather than collective. The discussion of a navigator's log as soon as possible after a flight is one of the most effective methods of instruction.

(ii) *Technical.*—The navigation officer is responsible for the calibration of altimeters and air speed indicators, and for supervising the care and adjustment of compasses (including those contained in bomb sights) and other navigational instruments. He may also be required to carry out or assist in service trials of new equipment used for or connected with air navigation, and should encourage the development of new methods of navigation.

(iii) *Administrative.*—(*a*) The navigation officer is responsible for the custody and correction of, and accounting for, all maps and charts held by the unit ; for the custody and correction of all publications issued for navigational purposes ; and for arranging that the information contained in these publications is accessible to all pilots and air gunners in the unit.

(*b*) The navigation officer should maintain a close liaison with the meteorological officer of his station. At stations where there is no meteorological staff, he will normally be responsible for making the weather observations required by the Meteorological Office in accordance with K.R. & A.C.I., para. 728, clause 5. He must also be able to decode the broadcast meteorological information and to compile the weather map.

### 2. The Navigation Office

For each unit at a modern R.A.F. station a navigation office is provided which, generally speaking, is used by the navigation officer as an office and store room for maps and charts, instructional instruments and calibrating instruments,



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which are kept on his charge. The office is not intended to be a lecture room for ground instruction. Ample table accommodation is necessary to allow for the correction of maps and charts.

### 3. The Pilots' Room

At modern R.A.F. stations a pilots' room is provided. It forms a convenient place for the meeting of officer and airman pilots where they can receive orders concerning training and operational flights, discuss the various methods of carrying them out and, after the flights, talk over what has happened. Large-scale maps of the country surrounding the aerodrome, air photographs and, during operations, maps of the operational areas and photographs of objectives should be displayed on the walls. Publications containing information for navigational purposes, such as the *Air Pilot, Notices to Airmen,* etc., should be kept in an accessible place in the pilots' room, together with a large-scale wall map on which aerodrome obstructions, danger areas and other important items of information are indicated as described in the next paragraph.

### 4. " Notices to Airmen " and " Notices to Mariners "

(i) Information concerning air navigation is given in *Notices to Airmen,* which are published periodically and distributed to units. In addition to permanent information chiefly affecting maps and charts the notices contain much information of a temporary nature, more or less urgent in character, as, for example, obstructions or bad surfaces to aerodromes, new danger areas, etc. In order that such information may be utilised, a wall map should be kept in the pilots' room. On it small paper flags or coloured pins should be fixed in the places affected, showing briefly the nature of the information, together with the number of the notice which gives the information in full. Near the map should be hung a file of Notices to Airmen : notices are most conveniently filed in numerical order. An index is published twice yearly showing the notices still effective, and this index is kept up to date by a monthly supplement to the Air Pilot (*see* para. 5). The index must be amended monthly as necessary, and notices no longer effective should be destroyed.

(ii) Where operational areas include the coast line, *Notices to Mariners,* which are published weekly, should be obtained. The information most likely to be of use will be notices regarding changes of the lights in light vessels and lighthouses.

(iii) Information concerning air navigation is also published from time to time in *Air Ministry Orders.* It is frequently distributed by W/T signals and published in *Station*

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*Daily Routine Orders*. Files containing the information published in Air Ministry Orders and Daily Routine Orders should be kept with the Notices to Airmen file.

### 5. "The Air Pilot" and "Coastal Air Pilot"

(i) *The Air Pilot* (*Great Britain and Ireland*) is issued to every squadron at home. It contains a great deal of miscellaneous information about flying, including details of prohibited and danger areas, airway lights and obstructions, etc., and schedules of all aerodromes and seaplane stations in Great Britain and Ireland. It is kept up to date by monthly supplements, and it is important that amendments, as necessary, should be made immediately the monthly supplement is received. A summary of the state of aerodromes is published in the supplement. The "Air Pilot" should be kept in the pilots' room in order that the information contained therein may be readily available to pilots.

(ii) *The Coastal Air Pilot* gives full details of seaplane harbours and emergency anchorages along the coasts of Great Britain.

### 6. Accounting for maps and charts

(i) One of the duties of the navigation officer of a unit is to maintain a record of the receipt, issue on loan and eventual disposal of all maps and charts in the unit (*see* K.R. & A.C.I., chapter XXX, section V).

(ii) A certain scale of issue of maps is laid down for each unit. A board of survey is held periodically to recommend for destruction such maps and charts as may be unfit for service. Demands for replacement of maps and charts written off by a board of survey should be forwarded in duplicate on Form 771 direct to the Map Section, Air Ministry. If demands are in excess of the scale of issue, they must be forwarded through the usual channels. The demand is given an issue voucher number and returned with the maps, and the original should be receipted and returned with the unit receipt voucher number entered on it, the duplicate being kept in the unit map account receipt file. Demands and receipts should be numbered consecutively throughout the year. An index should be kept of the receipt file, the following being a specimen :—

| *Demand No.* | *Date.* | *I.V. No.* | *Date.* | *R.V. No.* | *Date.* |
|---|---|---|---|---|---|
| 1/35 | 5.1.35 | 273 | 10.1.35 | 1/35 | 14.1.35 |
| — | — | 314 | 27.2.35 | 2/35 | 1.3.35 |
| 2/35 | 10.4.35 | 386 | 16.4.35 | 3/35 | 19.4.35 |

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(iii) Issues of maps are recorded in the same way, and a similar index kept. When a board of survey is held, the proceedings on Form 2 are given an issue voucher number and filed in the issue file. Temporary issues to individuals within the unit should be recorded on Loan Cards (Form 668). An up-to-date subsidiary summary of loans under the respective titles and sheet numbers also should be kept ; this will prove of use when the map and chart account is submitted for audit.

(iv) Lost maps may be written off charge by means of :—

(*a*) Form 664B. (loss statement), in cases where the loss is charged to an individual ; or

(*b*) Certificate of the C.O. that the loss has been investigated and the loss occurred by unavoidable accident for which blame is not attributable to any individual.

(v) A record of receipts and issues of maps and charts must be kept in the unit Map and Chart Account (Form 197) under the individual titles and sheet numbers of all maps and charts held on charge. For receipts, the date, origin (normally Map Section, Air Ministry) and the receipt voucher number must be entered ; for issues, the date, unit to which issued, and issue voucher number. When maps are written off by a board of survey, the " unit to which issued " will be " Board of Survey ".

The account should be checked periodically with the maps in stock and loan cards, and balanced out.

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## APPENDIX I

### CONVERSION OF ANGULAR MEASURES

1. To convert centesimal measure into sexagesimal measure :—

An angle written in terms of the centesimal method is expressed as a decimal fraction of a right angle.

Thus 90 g 28' 89'' = 0·902889 right angle
0·902889 right angle (× 90) = 81°·26001
0°·26001 (× 60) = 15'·6006
0'·6006 (× 60) = 36″ nearly.
Hence 90 g 28' 89'' = 81° 15' 36″.

2. To convert sexagesimal measure into centesimal measure :— For example, to express 81° 15' 36″ in centesimal measure.

36″ (÷ 60) = 0'·6
15'·6 (÷ 60) = 0°·26
81°·26 (÷ 90) = 0·902889 right angle (nearly).
Hence 81° 15' 36″ = 90 g 28' 89''.

3. To convert a longitude expressed in one system to a longitude expressed in the other system and referred to a different prime meridian :—For example, express the longitude of Calshot (4 g 04' 81'' W. of Paris) in sexagesimal measure referred to the meridian of Greenwich.

4 g 04' 81'' = ·040481 right angle = 3° 38' 36″
∴ Calshot is 3° 38' 36″ W. of Paris.
But Paris is 2° 20' 14″ E. of Greenwich
∴ Longitude of Calshot referred to Greenwich is
(3° 38' 36″ — 2° 20' 14″) or 1° 18' 22″ W.

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## APPENDIX II

### CALCULATION OF RHUMB LINE TRACK AND DISTANCE

The rhumb line track and distance between two places can be calculated by means of the following formulae :—

$$\tan \text{track} = \frac{d \text{ Long.}}{d \text{ meridional parts}}$$

distance (in nautical miles) = $d$ Lat. sec. track.

(Tables of meridional parts will be found in Inman's nautical tables.)

*Example* :—Find the rhumb line track and distance from Cranwell (Lat. 53° 02′ N., Long. 00° 30′ W.) to Hinaidi (Lat. 33° 17′ N., Long. 44° 30′ E.).

| | | | |
|---|---|---|---|
| Lat. of Cranwell | 53° 02′ N. | Mer. parts 3767·09 | Long. 00° 30′ W. |
| Lat. of Hinaidi | 33° 17′ N. | Mer. parts 2119·83 | Long. 44° 30′ E. |
| *d* Lat. | 19° 45′ S. = 1185′ S. | *d* Mer. parts 1647·26 | *d* Long. 45° 00′ E. = 2700′ E. |

| | |
|---|---|
| log *d* Long. | = 3·43136 |
| log *d* Mer. parts | = 3·21676 |
| log tan track | = 0·21460 |
| track | = S. 58° 37′ E. = 121° 23′ |
| log *d* Lat. | = 3·07372 |
| log sec. track | = 0·28336 |
| log distance (in nautical miles) | = 3·35708 |
| $\log \frac{6080}{5280}$ | = 0·06127 |
| log distance (in statute miles) | = 3·41835 |
| distance | = 2620·3 statute miles. |

For practical purposes, the track is taken to the nearest degree and the distance to the nearest mile, so that the required answer is :—

Track 121°, distance 2,620 miles.

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## APPENDIX III

### CONVERSION TABLE FOR LINEAR MEASURES

*Table* 1.—*British and Metric Units of Length*

| Geographical Miles. | Nautical Miles. | Statute Miles. | Kilometres. | Furlongs. | Chains. | Fathoms. | Metres. | Yards. | Feet. | Links. | Inches. | Centimetres. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1·0012 | 1·1529 | 1·8554 | 9·223 | 92·23 | 1,014·5 | 1,855·4 | 2,029·1 | 6,087·2 | 9,223·0 | 73,046 | 185,537 |
| — | 1 | 1·1515 | 1·8532 | — | — | 1,103·3 | 1,853·2 | 2,026⅔ | 6,080 | — | 72,960 | 185,318 |
| — | — | 1 | 1·6093 | 8 | 80 | 880 | 1,609·3 | 1,760 | 5,280 | 8,000 | 63,360 | 160,934 |
| — | — | — | 1 | 4·97 | 49·7 | 546·8 | 1,000 | 1,093·6 | 3,280·8 | 4,971 | 39,270 | 100,000 |
| — | — | — | — | 1 | 10 | 110 | 201·2 | 220 | 660 | 1,000 | 7,920 | 20,117 |
| — | — | — | — | — | 1 | 11 | 20·12 | 22 | 66 | 100 | 792 | 2,012 |
| — | — | — | — | — | — | 1 | 1·829 | 2 | 6 | 9 1/11 | 72 | 183 |
| | | | | | | | 1 | 1·0936 | 3·281 | 4·971 | 39·37 | 100 |
| | | | | | | | — | 1 | 3 | 4 6/11 | 36 | 91·44 |
| | | | | | | | — | — | 1 | 1·515 | 12 | 30·48 |
| | | | | | | | — | — | — | 1 | 7·92 | 20·12 |
| | | | | | | | — | — | — | — | 1 | 2·54 |

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*Table 2.—British, Metric and Russian Units of Length*

| Statute Mile. | Versts. | Kilometres. | Sajenyams. | Metres. | Yards. | Feet (Futam). | Inches (Dyuimam). | Centimetres. |
|---|---|---|---|---|---|---|---|---|
| 1 | 1·5086 | 1·6093 | 754·29 | 1,609·3 | 1,760 | 5,280 | 63,360 | 160,934 |
| | 1 | 1·0668 | 500 | 1,066·80 | 1,166·67 | 3,500 | 42,000 | 106,680 |
| | | 1 | 468·7 | 1,000 | 1,093·6 | 3,280·8 | 39,370 | 100,000 |
| | | | 1 | 2·1336 | 2·333 | 7 | 84 | 213·36 |

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## APPENDIX IV

### SCALES

1. A scale expressed as a statement in words may be readily converted to a representative fraction. Thus, on a scale of 4 miles to an inch, 1 inch represents (63,360 × 4) inches or 253,440 inches: then the representative fraction is 1/253,440.

2. To find the number of miles on the ground corresponding to 1 inch on the map for which the R.F. is given, divide the denominator of the R.F. by 63,360. Thus, if the R.F. be 1/80,000, the number of miles to the inch equals 80,000/63,360 = 1·26.

3. To find the number of inches on the map corresponding to 1 mile on the ground, divide 63,360 by the denominator of the R.F. If the R.F. be 1/80,000, the number of inches to 1 mile is 63,360/80,000 = 0·79.

4.—(i) It is often necessary to divide a line equally into a number of parts in order to construct a scale line. Taking line AB about 4·7 inches long, which is to be divided into five equal parts. From A draw AC at an angle of about 20° to AB. Along this mark off five equal distances, D, E, F, G, H. Join the last point H with B and from the other points of division draw lines cutting AB which are parallel to BH. (Fig. 116.)

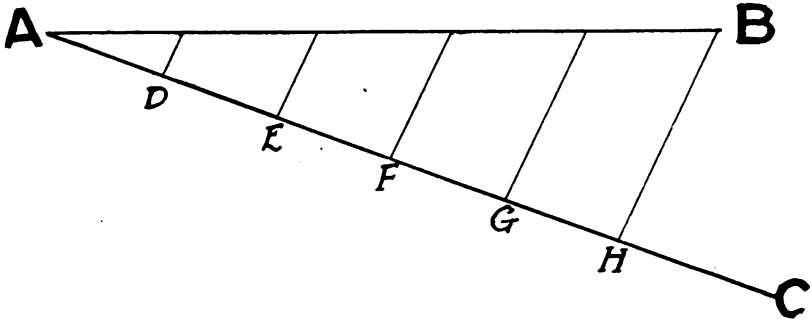


FIG. 116.—Scales—dividing a line into equal parts.

(ii) If the line to be divided is short, more accurate results may be obtained as shown in Fig. 117, e.g., to divide a line AB 1·3 inches long into eight equal parts. At A and B set up perpendiculars above and below the line; divide each perpendicular into seven equal parts of convenient length and join the points of division on the perpendiculars as shown.

5. Scales are of two kinds, technically described as fully divided and open divided. In the fully divided scale the smaller divisions, known as secondary divisions, are cut throughout the whole length of the scale, whereas in the open divided scale only one of the large or primary divisions is divided into secondary divisions. In the fully divided scale the zero is placed at the extreme left. In the open divided scale, on the other hand, the secondary scale is always an extension to the left from the zero of the primary scale. Thus, the secondary scale is read from zero towards the left. Examples of the construction of scales are given.

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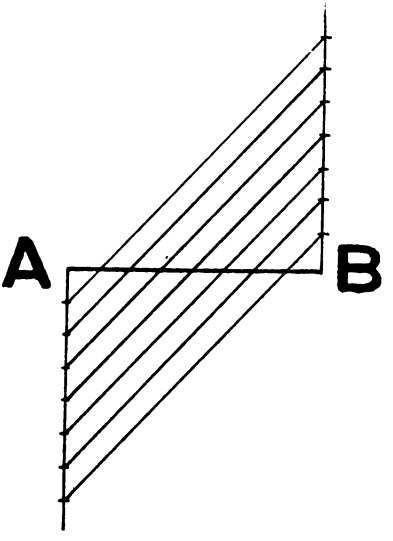


FIG. 117.—Scales—dividing a short line into equal parts.

*Example.*—To construct a scale of 2 inches to a mile to show hundreds of yards.

The R.F. = 2/63,360 = 1/31,680.

To show 5,000 yards the length of the scale line must be 5,000 × 36/31,680 inch = 5·68 inches.

Draw a line 5·68 inches long, divide it into 5 primary divisions and sub-divide the first primary division into 10 secondary divisions.

The scale is then completed, as in Fig. 118.

*Example.*—To construct a scale of 1/M to show miles (M = million).

1 mile is represented by 63,360/1,000,000, or 0·0634 inch.

Then 100 miles is represented by 6·34 inches.

Draw a line 6·34 inches long, divide it into 10 primary divisions and sub-divide the first primary division into 10 secondary divisions. (Fig. 119.)

*Example.*—To construct a scale for use with a ¼-in. map to show kilometres.

From a conversion table 1 Km. = 0·62 mile, so that 1 Km. is represented by 0·155 inch.

Then 40 Kms. is represented by 6·2 inches.

Draw a line 6·2 inches long, divide it into 4 primary divisions and sub-divide a primary division into 10 secondaries, as Fig. 120.

6. *Time scales* may be made with reference to the scale of the particular map being used and to the ground speed. Consider, for example, a scale to show intervals of 10 minutes for a ground speed of 72 miles per hour on a map of which the scale is 10 miles to an inch.

In 10 minutes 72/6 or 12 miles are covered.

Twelve miles is represented on the map by 1·2 inches.

Then, if a line is drawn and divisions of 1·2 inches marked upon it, the divisions may be numbered 0, 10, 20 . . . minutes, and the scale is completed. (Fig. 121.)

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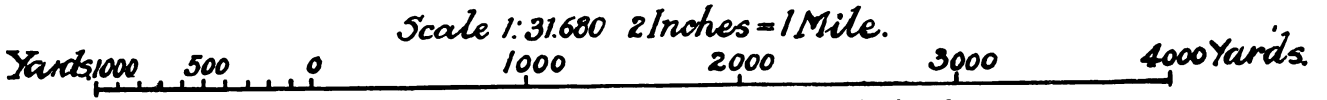


FIG. 118.—Scale of 2 in. to 1 mile to show humdreds of yards.

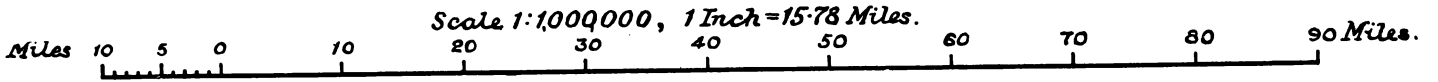


FIG. 119.—Scale of 1/1,000,000 to show miles.

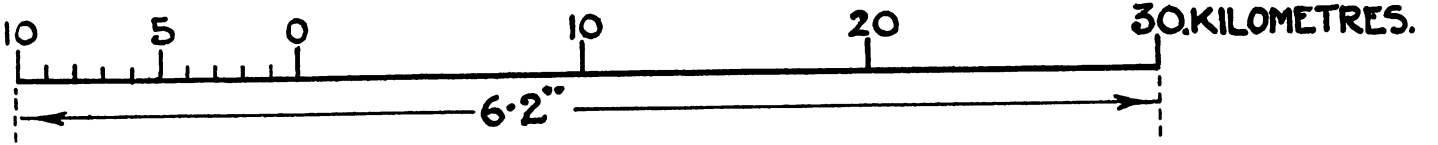


FIG. 120.—Scale for ¼-in. map to show kilometers.

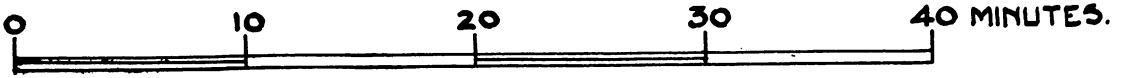


FIG. 121.—Time scale.



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7. A diagram may easily be prepared to give a time scale for any ground speed with reference to a given map scale. On Fig. 122 time scales for ground speeds from 60 to 160 miles per hour on a ¼-inch to the mile map are shown. The diagram is constructed as follows :—

Draw a vertical line and divide it into eight equal parts, writing ground speeds against the divisions. Draw horizontal lines from each division. Now a speed of 60 miles an hour equals 1 mile a minute, and 1 mile is represented by ¼ inch ; 120 miles an hour equals 2 miles a minute, and 2 miles are represented by ½ inch. Then if the horizontal line 60 be divided into ¼ inches and the 120 line into ½ inches, these divisions will be minutes. The diagram is completed by drawing lines through the corresponding graduations on the 60 and 120 lines.

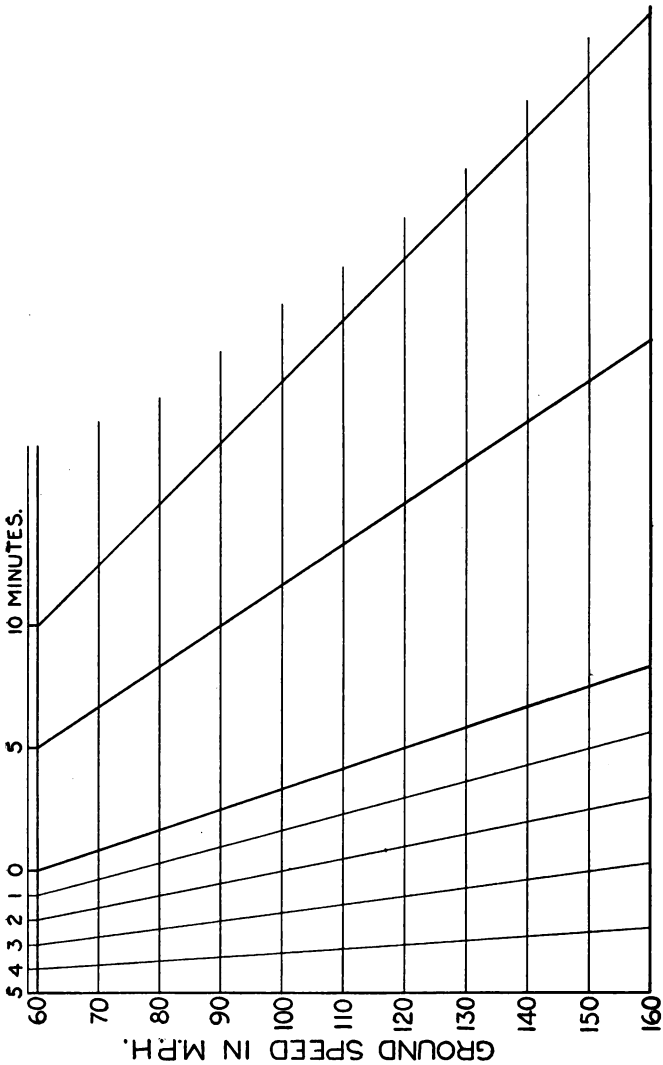


FIG. 122.—Time scale for any ground speed.

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| | COMBINED SYMBOLS |
|---|---|
| | CROYDON |
| | |
| | |
| acon station | |
| | |
| | |
| | |
| autical W/T ion. | |
| uction. | |

War Office. 1935.

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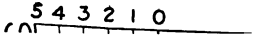


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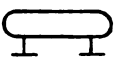
## APPENDIX VI

### TABLE OF CONVENTIONAL SIGNS TO BE USED IN MARKING MAPS AND DIAGRAMS

In order to provide a means of marking maps, diagrams, etc., clearly and rapidly, the following conventional signs have been adopted for use in the Royal Air Force :—

| | | |
|---|---|---|
| Squadrons | Fighter .. .. | |
| | Army Co-operation .. | |
| | Naval Co-operation unit. | |
| | Day bomber .. | |
| | Night bomber .. | |
| Repair and maintenance units. | Air stores park .. | |
| | Aircraft depot .. | |
| | Port detachment .. | |
| Headquarters of formations | Wing H.Q. .. | |
| | Group H.Q. .. .. | |
| | R.A.F. H.Q. .. | |
| Captive balloon .. .. | .. .. .. | |
| Airship .. .. .. | .. .. .. |  |



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## APPENDIX VII

### VALUES OF CONVERSION ANGLE

($\frac{1}{2}$ d. longitude = 1°.)

| Middle Latitude. | Conversion Angle. |
|---|---|
| 49° .. .. .. .. | 45′ |
| 50° .. .. .. .. | 46′ |
| 51° .. .. .. .. | 47′ |
| 52° .. .. .. .. | 47′ |
| 53° .. .. .. .. | 48′ |
| 54° .. .. .. .. | 49′ |
| 55° .. .. .. .. | 49′ |
| 56° .. .. .. .. | 50′ |
| 57° .. .. .. .. | 50′ |
| 58° .. .. .. .. | 51′ |
| 59° .. .. .. .. | 51′ |

## APPENDIX VIII

### CONVERSION TABLE FOR PRESSURE

| Inch. | Millimetre. | Millibars. |
|---|---|---|
| 1 | 25·4 | 33·9 |
| 0·0394 | 1 | 1·33 |
| 0·0295 | 0·75 | 1 |



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## APPENDIX IX

### TABLE FOR FINDING THE SPEED OF THE WIND BY FLYING UP-WIND AND TURNING THROUGH 90°

The speed of the wind is taken out from the column headed by the air speed of the aircraft opposite the angle of drift observed. Thus, if the air speed were 120 m.p.h. and the drift 12°, the speed of the wind would be 26 m.p.h. The wind speed is correct to the nearest mile an hour.

| Wind Speed. | Air Speed. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Angle of Drift. | 90. | 100. | 110. | 120. | 130. | 140. | 150. | 160. | 170. | 180. |
| 2° | 3 | 3 | 4 | 4 | 5 | 5 | 5 | 6 | 6 | 6 |
| 4° | 6 | 7 | 8 | 8 | 9 | 10 | 10 | 11 | 12 | 13 |
| 6° | 9 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| 8° | 13 | 14 | 15 | 17 | 18 | 20 | 21 | 22 | 24 | 25 |
| 10° | 16 | 18 | 19 | 21 | 23 | 25 | 26 | 28 | 30 | 32 |
| 12° | 19 | 21 | 23 | 26 | 28 | 30 | 32 | 34 | 36 | 38 |
| 14° | 22 | 25 | 27 | 30 | 32 | 35 | 37 | 40 | 42 | 45 |
| 16° | 26 | 29 | 31 | 34 | 37 | 40 | 43 | 46 | 49 | 52 |
| 18° | 29 | 32 | 36 | 39 | 42 | 45 | 49 | 52 | 55 | 58 |
| 20° | 33 | 36 | 40 | 44 | 47 | 51 | 55 | 58 | | |
| 22° | 36 | 40 | 44 | 49 | 53 | 57 | 61 | | | |
| 24° | 40 | 44 | 49 | 53 | 58 | | | | | |
| 26° | 44 | 49 | 54 | 58 | | | | | | |
| 28° | 48 | 53 | 58 | | | | | | | |
| 30° | 52 | 58 | | | | | | | | |

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## APPENDIX X

### TABLES FOR FINDING THE SPEED OF THE WIND BY THE RECIPROCAL COURSE METHOD (*see* chapter VIII, para. 8)

| Wind Speed in m.p.h. | 3-minute Courses. Air Speed. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Time in Minutes and Seconds. | 95. | 100. | 105. | 110. | 115. | 120. | 125. | 130. | 135. | 140. |
| 0·15 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 6 |
| 0·30 | 7 | 8 | 8 | 8 | 9 | 9 | 10 | 10 | 10 | 11 |
| 0·45 | 11 | 11 | 12 | 12 | 13 | 13 | 14 | 14 | 15 | 16 |
| 1·00 | 14 | 14 | 15 | 16 | 16 | 17 | 18 | 19 | 19 | 20 |
| 1·15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 22 | 23 | 24 |
| 1·30 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| 1·45 | 21 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| 2·00 | 24 | 25 | 26 | 27 | 29 | 30 | 31 | 32 | 34 | 35 |
| 2·15 | 26 | 27 | 28 | 30 | 31 | 33 | 34 | 35 | 37 | 38 |
| 2·30 | 28 | 29 | 31 | 32 | 34 | 35 | 37 | 38 | 40 | 41 |
| 2·45 | 30 | 31 | 33 | 35 | 36 | 38 | 40 | 41 | 43 | 44 |
| 3·00 | 32 | 33 | 35 | 37 | 38 | 40 | 42 | 43 | 45 | 47 |
| 3·15 | 33 | 35 | 37 | 39 | 40 | 42 | 44 | 46 | 47 | 49 |
| 3·30 | 35 | 37 | 39 | 41 | 42 | 44 | 46 | 48 | 50 | 51 |
| 3·45 | 37 | 38 | 40 | 42 | 44 | 46 | 48 | 50 | 52 | 54 |
| 4·00 | 38 | 40 | 42 | 44 | 46 | 48 | 50 | 52 | 54 | 56 |
| 4·30 | 41 | 43 | 45 | 47 | 49 | 51 | 53 | 56 | 58 | 60 |
| 5·00 | 43 | 45 | 48 | 50 | 52 | 54 | 57 | 59 | 61 | |
| 5·30 | 45 | 48 | 50 | 53 | 55 | 57 | 60 | | | |
| 6·00 | 47 | 50 | 52 | 55 | 57 | 60 | | | | |
| 7·00 | 51 | 54 | 56 | 59 | 62 | | | | | |
| 8·00 | 54 | 57 | 60 | | | | | | | |
| 9·00 | 57 | 60 | | | | | | | | |
| 10·00 | 59 | 62 | | | | | | | | |

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| Wind Speed in m.p.h. | 5-minute Courses. Air Speed. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Time in Minutes and Seconds. | 95. | 100. | 105. | 110. | 115. | 120. | 125. | 130. | 135. | 140. |
| 0·15 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| 0·30 | 5 | 5 | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 7 |
| 0·45 | 7 | 7 | 7 | 8 | 8 | 8 | 9 | 9 | 9 | 10 |
| 1·00 | 9 | 9 | 10 | 10 | 10 | 11 | 11 | 12 | 12 | 13 |
| 1·15 | 11 | 11 | 12 | 12 | 13 | 13 | 14 | 14 | 15 | 16 |
| 1·30 | 12 | 13 | 13 | 14 | 15 | 16 | 16 | 17 | 18 | 18 |
| 1·45 | 14 | 15 | 16 | 16 | 17 | 18 | 19 | 19 | 20 | 21 |
| 2·00 | 16 | 17 | 17 | 18 | 19 | 20 | 21 | 22 | 22 | 23 |
| 2·15 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| 2·30 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| 2·45 | 20 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| 3·00 | 22 | 23 | 24 | 25 | 26 | 28 | 29 | 30 | 31 | 32 |
| 3·15 | 23 | 25 | 26 | 27 | 28 | 29 | 31 | 32 | 33 | 34 |
| 3·30 | 24 | 26 | 27 | 28 | 29 | 31 | 34 | 34 | 35 | 36 |
| 3·45 | 26 | 27 | 29 | 30 | 31 | 33 | 34 | 35 | 37 | 38 |
| 4·00 | 27 | 29 | 30 | 31 | 32 | 34 | 36 | 37 | 39 | 40 |
| 4·30 | 29 | 31 | 32 | 34 | 35 | 37 | 39 | 40 | 42 | 43 |
| 5·00 | 31 | 33 | 35 | 37 | 38 | 40 | 42 | 43 | 45 | 47 |
| 5·30 | 34 | 35 | 37 | 39 | 41 | 43 | 44 | 46 | 48 | 50 |
| 6·00 | 36 | 38 | 40 | 42 | 43 | 45 | 47 | 49 | 50 | 52 |
| 7·00 | 39 | 41 | 43 | 45 | 47 | 49 | 51 | 53 | 55 | 58 |
| 8·00 | 42 | 44 | 46 | 49 | 51 | 53 | 55 | 58 | 60 | |
| 9·00 | 45 | 47 | 49 | 52 | 54 | 57 | 59 | 62 | | |
| 10·00 | 47 | 50 | 52 | 55 | 57 | 60 | | | | |

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## APPENDIX XI

### TABLE FOR FINDING THE ERROR IN THE TRACK

The error is taken out from the column headed by the distance from the required track opposite the distance run. Thus if the distance from the required track is 3 miles and the distance run is 35 miles, the error is 5°.

| Distance run in miles. | Error in Track. | Distance from Required Track in miles. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. |
| | 5 | 11° | 22° | | | | | | | | |
| | 6 | 9° | 18° | 27° | | | | | | | |
| | 7 | 8° | 16° | 24° | 30° | | | | | | |
| | 8 | 7° | 14° | 21° | 27° | | | | | | |
| | 9 | 6° | 13° | 18° | 24° | 29° | | | | | |
| | 10 | 6° | 11° | 17° | 22° | 27° | 31° | | | | |
| | 12 | 5° | 9° | 14° | 18° | 23° | 27° | 30° | | | |
| | 14 | 4° | 8° | 12° | 16° | 20° | 24° | 27° | 30° | | |
| | 16 | 4° | 7° | 11° | 14° | 17° | 21° | 24° | 27° | 29° | |
| | 18 | 3° | 6° | 9° | 13° | 16° | 18° | 21° | 24° | 27° | 29° |
| | 20 | 3° | 6° | 9° | 11° | 14° | 17° | 19° | 22° | 24° | 27° |
| | 25 | 2° | 5° | 7° | 9° | 11° | 13° | 16° | 18° | 20° | 22° |
| | 30 | 2° | 4° | 6° | 8° | 10° | 11° | 13° | 15° | 17° | 18° |
| | 35 | 2° | 3° | 5° | 6° | 8° | 10° | 11° | 13° | 15° | 16° |
| | 40 | 1° | 3° | 4° | 6° | 7° | 9° | 10° | 11° | 13° | 14° |
| | 45 | 1° | 2° | 4° | 5° | 6° | 8° | 9° | 10° | 11° | 13° |
| | 50 | 1° | 2° | 3° | 5° | 6° | 7° | 8° | 9° | 10° | 11° |
| | 60 | 1° | 2° | 3° | 4° | 5° | 6° | 7° | 8° | 9° | 10° |
| | 70 | 1° | 2° | 2° | 3° | 4° | 5° | 6° | 7° | 7° | 8° |
| | 80 | 1° | 1° | 2° | 3° | 4° | 4° | 5° | 6° | 6° | 7° |
| | 90 | | 1° | 2° | 3° | 3° | 4° | 4° | 5° | 6° | 6° |
| | 100 | | 1° | 2° | 2° | 3° | 3° | 4° | 5° | 5° | 6° |
| | 120 | | 1° | 1° | 2° | 2° | 3° | 3° | 4° | 4° | 5° |
| | 140 | | 1° | 1° | 2° | 2° | 2° | 3° | 3° | 4° | 4° |
| | 160 | | 1° | 1° | 1° | 2° | 2° | 2° | 3° | 3° | 4° |

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## APPENDIX XII

### RADIUS OF ACTION

The approximate radius of action for one hour is given :—

| Air Speed. Radius of Action. | Speed of Wind. 5. | 10. | 15. | 20. | 25. | 30. | 35. | 40. |
|---|---|---|---|---|---|---|---|---|
| 90 | 45 | 44 | 44 | 43 | 42 | 41 | 40 | 38 |
| 95 | 47 | 47 | 47 | 46 | 45 | 44 | 43 | 41 |
| 100 | 50 | 50 | 49 | 48 | 48 | 47 | 45 | 44 |
| 105 | 52 | 52 | 52 | 51 | 50 | 49 | 48 | 47 |
| 110 | 55 | 55 | 54 | 54 | 53 | 52 | 51 | 49 |
| 115 | 57 | 57 | 57 | 56 | 55 | 55 | 54 | 52 |
| 120 | 60 | 60 | 59 | 59 | 58 | 57 | 56 | 55 |
| 125 | 62 | 62 | 61 | 61 | 60 | 59 | 58 | 57 |
| 130 | 65 | 64 | 64 | 63 | 62 | 61 | 60 | 59 |
| 135 | 67 | 67 | 66 | 66 | 65 | 64 | 63 | 62 |
| 140 | 70 | 69 | 69 | 68 | 68 | 67 | 66 | 64 |
| 145 | 72 | 72 | 71 | 71 | 70 | 69 | 68 | 67 |
| 150 | 75 | 75 | 74 | 74 | 73 | 72 | 71 | 70 |
| 155 | 77 | 77 | 77 | 76 | 75 | 75 | 73 | 72 |
| 160 | 80 | 80 | 79 | 79 | 78 | 77 | 76 | 75 |
| 165 | 82 | 82 | 81 | 81 | 81 | 80 | 79 | 78 |
| 170 | 85 | 85 | 84 | 84 | 83 | 82 | 81 | 80 |
| 175 | 87 | 87 | 87 | 86 | 86 | 85 | 84 | 83 |
| 180 | 90 | 90 | 89 | 89 | 88 | 87 | 86 | 85 |
| 185 | 92 | 92 | 92 | 91 | 91 | 90 | 89 | 88 |
| 190 | 95 | 95 | 94 | 94 | 93 | 93 | 92 | 91 |
| 195 | 97 | 97 | 97 | 96 | 96 | 95 | 94 | 93 |
| 200 | 100 | 100 | 99 | 99 | 98 | 98 | 97 | 96 |

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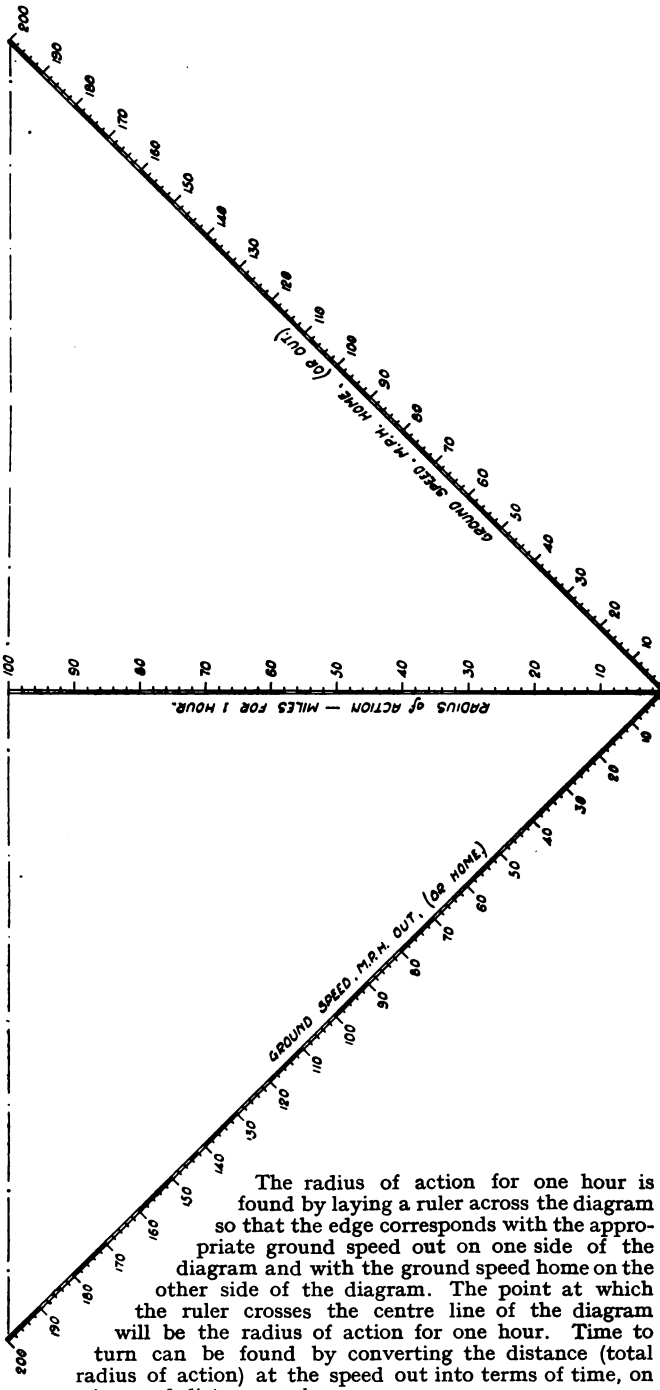


Total radius of action = radius of action for one hour × petrol-hours capacity of aircraft (allowing a margin for climb and reserve).

FIG. 123.—Diagram for finding the radius of action.

The radius of action for one hour is found by laying a ruler across the diagram so that the edge corresponds with the appropriate ground speed out on one side of the diagram and with the ground speed home on the other side of the diagram. The point at which the ruler crosses the centre line of the diagram will be the radius of action for one hour. Time to turn can be found by converting the distance (total radius of action) at the speed out into terms of time, on a time and distance scale.

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## APPENDIX XIII

### QUADRANTAL ERROR CORRECTION CURVE

The magnetic bearing of the transmitting station being known, the aircraft is placed successively on various magnetic courses and the scale reading obtained on each course is noted. By applying the scale reading to the course, the W/T bearing of the transmitting station is obtained and any quadrantal error is at once obvious. The accuracy of the correction curve depends upon careful observations and upon the number of courses upon which scale readings are taken. In the example below, readings were taken for twelve courses : if time allows a larger number is to be preferred.

Magnetic bearing of station : 143°.

| Magnetic Course of Aircraft. | Scale Reading. | W/T Bearing of Transmitting Station. | Correction to Scale Reading. |
|---|---|---|---|
| 63° | 68° G | 131° | +12 |
| 92° | 42° G | 132° | +11 |
| 126° | 11° G | 137° | + 6 |
| 149° | 6° R | 143° | 0 |
| 192° | 38° R | 154° | +11 |
| 241° | 94° R | 147° | + 4 |
| 265° | 50° G (130° R) | 135° | − 8 |
| 308° | 15° G (165° R) | 143° | 0 |
| 343° | 16° R (164° G) | 147° | − 4 |
| 18° | 51° R (129° G) | 147° | − 4 |
| 56° | 76° G | 132° | +11 |

From this table, the curve is plotted as shown in Fig. 124.

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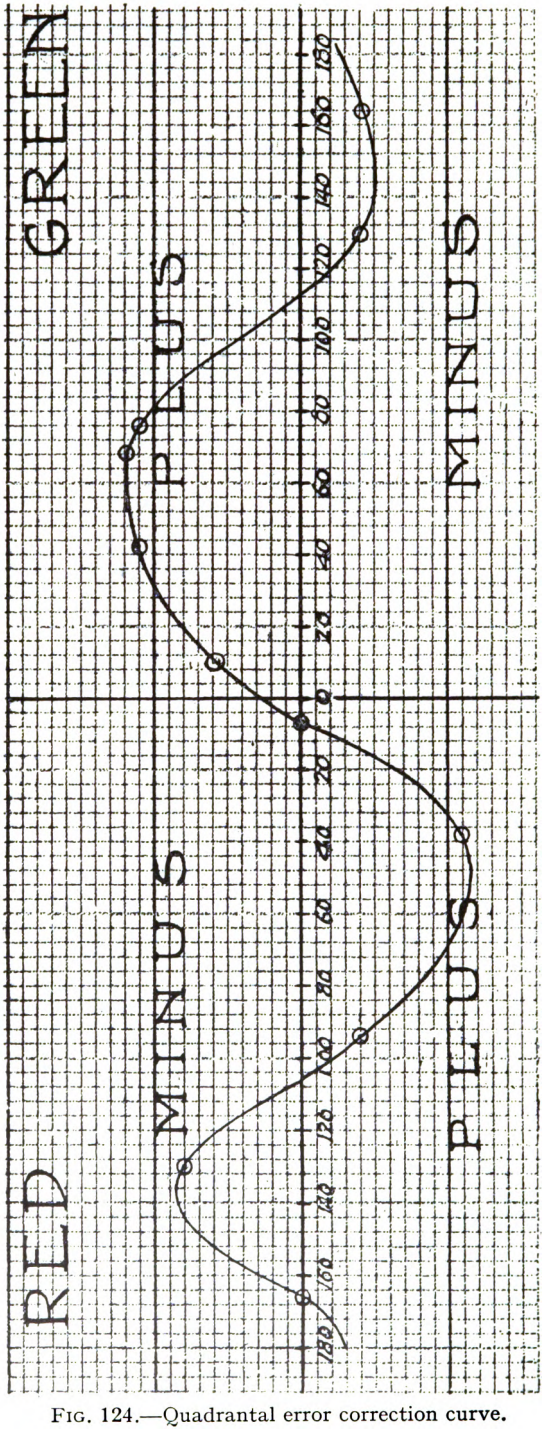


FIG. 124.—Quadrantal error correction curve.

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## APPENDIX XIV

### THE BEAUFORT SCALE OF WIND FORCE WITH SPECIFICATIONS AND EQUIVALENTS

| Beaufort Number. | General Description of Wind. | Specification of Beaufort Scale. | | Limits of Velocity in Miles per Hour at about 30 feet above level ground. |
|---|---|---|---|---|
| | | For Coast use.* | For use Inland. | |
| 0 | Calm | Calm .. .. | Smoke rises vertically | Less than 1 |
| 1 | Light air | Fishing smack just has steerage way. | Wind direction shown by smoke drift but not by wind vanes. | 1–3 |
| 2 | Light breeze. | Wind fills the sails of smacks, which then move at about 1–2 miles per hour. | Wind felt on face; leaves rustle; ordinary vane moved by wind. | 4–7 |
| 3 | Gentle breeze. | Smacks begin to careen and travel about 3–4 miles per hour. | Leaves and small twigs in constant motion; wind extends light flag. | 8–12 |
| 4 | Moderate breeze. | Good working breeze; smacks carry all can-vas with good list. | Raises dust and loose paper; small branches are moved. | 13–18 |
| 5 | Fresh breeze. | Smacks shorten sail | Small trees in leaf begin to sway. | 19–24 |
| 6 | Strong breeze. | Smacks have double reef in main sail. | Large branches in motion; whistling in telegraph wires. | 25–31 |
| 7 | Moderate gale. | Smacks at sea lie to. | Whole trees in motion | 32–38 |
| 8 | Fresh gale | All smacks make for harbour. | Breaks twigs off trees; generally impedes progress. | 39–46 |
| 9 | Strong gale | .. .. .. | Slight structural damage occurs; chimney pots removed. | 47–54 |
| 10 | Whole gale | .. .. .. | Trees uprooted; considerable structural damage. | 55–63 |
| 11 | Storm | .. .. .. | Very rarely experienced; widespread damage. | 64–75 |
| 12 | Hurricane | .. .. .. | .. .. .. | Above 75 |

* The fishing smack in this column may be taken as representing a trawler of average type and trim.

(26117) Wt 176/9 7500 8/35 Hw G.371.

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# ORTS FOR A

## Code for Weather at a charac

*00–19 Abbreviated description and special phenom*

00 Cloudless.
01 Partly cloudy.

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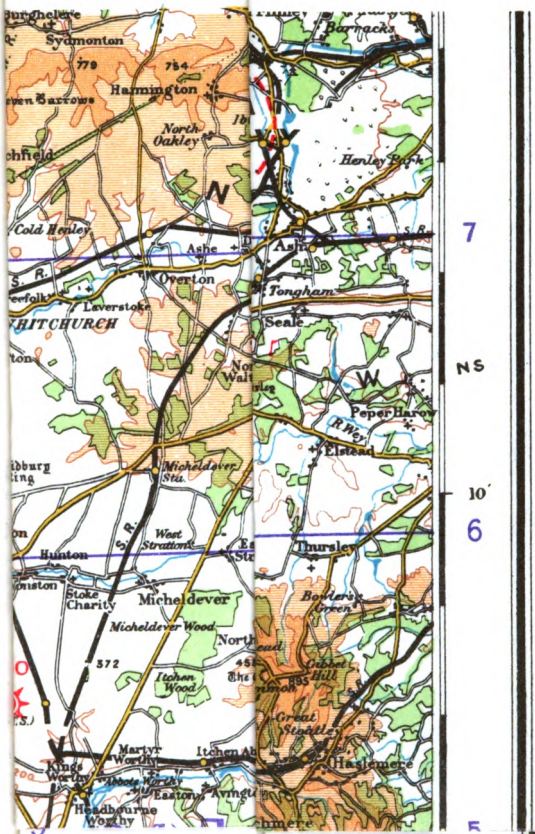
FORCE E

RT OF SHEET 11.




Ordnance Survey. 1935.

o One Mile - $\frac{1}{253440}$

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...ter High Water, and 3 hours Ebb are both indicated by .....

..... Low ..... , and 4 hours Flood .....

Swamp or Marsh (Salt or Mossy Land

...urrents and Tidal Streams is expressed in knots, thus :- ..... 1 km 5 km

...is given above the Datum of the chart.

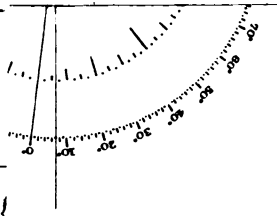
...which soundings are reduced, unless otherwise stated, is generally approximately Mean Low Water of Spring Tides.

Sand Hills or Dunes

Indian Spring Low Water. For definition see Admiralty Tide Tables, Part I.

Towns, Villages or Houses

Villages or Houses



Roads

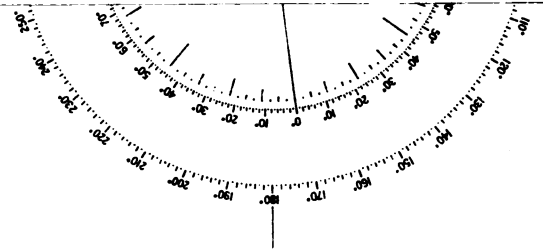
Track or Footpath

Railway

Tramway

...ckets, either before or after the ...e year for which it is given.

...e Magnetic, except when ..., and are referred to the ...on the Chart.



Note:- When a compass of the above pattern is shown on the chart, Bearings are given True thus:- 298°. unless otherwise stated in the Title. The figures in brackets after the Variation denote the year for which it is given.

Small corrections 1932 [3 7]-[8 8]-19...

1910. 28th Dec.r 1911, 19th June 1914, 7th May 1915, 18th July 1921, 22nd Jan. 1923, June 1923. 4th May 1928, 22nd Jan. 1932.

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